THE EFFECTS OF AMENDMENTS ON PROPERTIES OF MULCHED SANDY SOIL AND ON GROWTH OF TOMATO AND CUCUMBER

BY

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To the memory of my father, Vicente,
and to my mother, Maria de Lourdes,
this work is dedicated.

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Field studies were conducted during the Spring and Fall seasons in 1982 and 1983 on a limed, Mulat fine sand (Typic Ochraquults) to evaluate the effect of organic and inorganic amendments on growth of tomato (Lycopersicum esculemtum Mill) and cucumber (Cucumis sativus L.) in sequence on full-bed plastic mulch. In the 1982 tomato experiment, sewage sludge (SS), poultry manure (PM), Florida peat (FP), anaerobically digested cow manure (CM) applied at 22.4 Mg.ha^{-1} and fertilizer only (FO) received 1400 or 2800 kg.ha^{-1} of 6-3.5-6.6 (NPK) fertilizer containing ^{15}N-depleted ammonium sulfate. In 1983, SS and PM at 11.2 and 22.4 Mg.ha^{-1}, bentonite clay (BC) at 1.12 and 2.24 Mg.ha^{-1} and fertilizer at 0, 1400, 2800 and 4200 kg.ha^{-1} were combined in a semi-complete factorial. After harvesting of the tomato crops, no additional fertilizer was applied for cucumber except that in 1983 one-half of each plot received liquid NK fertilization.

Tomato fruit yields in both years were highest where PM and SS were used in combination with fertilizer. The first year, average percentages of N derived from fertilizer were 7, 10, 21, 25, and 35 in leaf and 9, 11, 23, 30, and 33 in fruit where soil amendments were SS, PM, FP, CM, and FO, respectively. Loss of fertilizer was attributed to leaching early in the 1982 season. Residual soil fertility was indicated by highest cucumber yields where PM and SS were applied in 1982; corresponding residual effect on cucumber yield was lower in 1983. Additional NK fertilizer had little effect on cucumber yield. Nitrate production, CO_2-C evolution, pH, EC, OM, and CEC were highest for soil amended with PM and SS.

Cadmium, Zn, and Cu increased in tomato leaf and fruit tissue when SS was utilized. Cadmium level in SS in 1983 was 55 $mg.kg^{-1}$. Tomato leaf and fruit tissue averaged 4.5 $mg.kg^{-1}$ and 25.6 $\mu g.kg^{-1}$, respectively, showing the exclusion of Cd from the fruit. Organic amendments may need supplemental fertilizer to assure a balanced supply of nutrients for tomato and subsequent cucumber requirements.

INTRODUCTION

The production and marketing of vegetables in Florida has become a major segment of the state's economy. In the 1980-81 season, vegetables were grown on more than 161,000 ha, and had a farm value exceeding 862 million dollars. Florida has produced the major supply in the U.S.A. of fresh market tomatoes during the late fall, winter, and early spring marketing seasons (IFAS, Vegetable Crops Committee Report, 1983). Tomatoes for fresh market were generally produced on sandy soils with high rates of N, P, and K fertilizer, and other intensive production practices (Everett, 1976; Persuad et al., 1976; Maynard and Locascio, 1982).

In 1980, Florida produced 127,000 tons of cucumber on 8,788 hectares, for a total value of 45.7 million dollars. Cucumber slicers were grown on 5,872 ha and another 2,916 ha were devoted to production of pickling cucumbers (IFAS, Vegetable Crops Committee Report, 1983). Most of the cucumber production was open-bed culture although some growers used full-bed plastic mulch. Where mulch culture was used for a first crop such as tomato, cucumber might follow for utilization of residual fertilizer.

As petroleum-based products have increased in cost, there probably could be an increase in utilization of multiple-cropping systems, to share production cost. Crop residues, animal manure, municipal sewage sludge and, more recently, food processing wastes, might be used to improve efficiency of fertilizer efficiency by vegetable crops. It would be unlikely that organic waste could be used to supply the total nutrient requirements of crops, because of the large amounts that would have to be applied. The greatest potential value of these materials for vegetable production may be realized as they are used in combination with inorganic fertilizer. In addition to providing partial fulfillment of the crop nutrient requirements, the organic wastes are valuable organic resources for improving the tilth and productivity of the soil.

The objectives of this research were 1) to evaluate the response of tomato productivity to amendments and fertilizer levels; 2) to use ^{15}N-depleted fertilizer to evaluate the distribution of fertilizer N in tomato-cucumber cropping system as affected by amendments and N levels; 3) to evaluate the response of cucumber productivity to residual soil fertility following the tomato crop; 4) to evaluate soil factors affecting nutrient uptake and distribution in tomato and cucumber crops as influenced by amendments and fertilizer levels; and 5) to determine the concentration of metals in edible and diagnostic tissue of tomato and cucumber plants grown on soil amended with sewage sludge, poultry manure, and clay.

LITERATURE REVIEW

Soil Amendments and Crop Response

Organic materials, including green manures, have been preferentially used, especially in developing countries. About 1960, these countries followed the lead of more advanced countries and used mineral fertilizer which has gained in popularity. As technical progress was made, mineral fertilizer became both more easily available and cheaper. The fertilizer materials and mixed fertilizers were relatively easy to transport and store. The use of inorganic fertilizer produced more effective and quicker results for the various crops than did organic materials.

Due to the world energy crisis and increased oil prices, inorganic fertilizers became less available and considerably more expensive so that it was important for fertilizer resources to be used efficiently. Use of inorganic or organic fertilizers are complementary, but much more use may be made of organic resources than presently is done.

Today, the consensus is that proper management of organic wastes such as crop residues, animal manures, and sewage sludges, as soil amendment, are essential for protecting agricultural soils from depletion of soil organic matter. Such loss from the soil has led to soil erosion and nutrient losses through runoff. Efficient and effective use of these organic materials also is known to be one of the best means available for maintaining soil productivity by recycling plant nutrients and by improving soil physical properties (Allison, 1973a).

Sewage Sludge

Sewage sludge is a by-product of the treatment of domestic and municipal waste water. The solids content of sludges varies and tends to increase with the degree of treatment. Primary and secondary sewage effluents contain bonded water and settle out slowly. These effluents have solids content that ranges from 1 to 5 $g.kg^{-1}$. Digested sludges characteristically retain less water and solids content commonly ranges from 60 to 120 $g.L^{-1}$.

Because sewage sludge is formed on aggregation of impurities originating in waste water, the chemical composition is influenced by sources of water input. The kind and extent of sewage treatments, as well as the nature of the sewage treatment process, are some of the factors affecting sewage sludge composition (Sommers et al., 1976). The chemical composition of sludges was evaluated in various studies (Berrow and Webber, 1972; Sommers et al., 1976; Sommers, 1977). They found high variability between many sources of sludge studied.

Large quantities of sewage sludge are produced annually in the United States under diverse climatic conditions. Disposal of sludges is becoming a serious problem. Recycling of sewage sludge on agricultural lands seems to be an important part of waste disposal (Carlson and Menzies, 1971; Parr and Willson, 1980; Cebula, 1982). Many greenhouse and field experiments point out the significant value of the sludge as fertilizer (Milne and Graveland, 1972; Sommers, 1977). They report that it enhances growth and yields of crops (Hinesly et al., 1972; Cunningham et al., 1975; Kelling et al., 1977a; Sheaffer et al., 1979). Other studies found that sludge treatment increases the nutrient contents in the soil (King and Morris, 1972; Kelling et al., 1977b; Sommers et al., 1979; Magdoff and Amadon, 1980). Sludge can improve soil aggregation (Epstein, 1975), soil water holding capacity (Gupta et al., 1977; Hall and Coker, 1981). Sludge also increased the soil population of bacteria and actinomycetes (McIlveen and Cole, 1977; Micthell et al., 1978b) and provides organic matter to the soil (Micthell et al., 1977; Diez, 1982). However, application of excessive amounts of sewage sludge creates a potential for contamination of ground water by NO_3-N (King and Morris, 1974; Schalscha et al., 1979), or may increase soil soluble salts (Epstein et al., 1976; Guidi et al., 1981). Other workers have studied the effects of sludge amendments on the increase in soil concentration and plant uptake of heavy metals (Page et al., 1972; Baker et al., 1975; Jones et al., 1975; Bingham et al., 1979; Valdares et al., 1983).

Data about metal uptake by vegetable crops grown in sludge-amendment soils are limited. Dowdy and Larson (1975) investigated the effect of sludge treatments on metal accumulation in the edible tissue of seven vegetable crops. They reported small but significant increase in the Zn and Cu content of edible fruit tubers and root tissues, whereas Cu and Pb levels remained unchanged, although metal accumulation was much greater in the leaf tissue. Giordono et al. (1975) also found higher metal levels in vegetative tissue than storage tissue for different vegetable crops. They point out that bush beans (Phaseolus vulgaris) were more sensitive to excessive soil Zn concentration, and moderately sensitive to soil Cd levels. They also found that high levels of Cd did not accumulate in the seed tissue. Micthell et al.

(1978a) reported that Ni was more phytotoxic to lettuce (*Lactuca sativa* L. var. longifolia) and wheat (*Triticum aestivum* L.) grown in acid soils than in calcareous soils. They noted that Cd, Cu and Zn toxicity depended on the plant species and range of metal concentration in the sludge. Zwarich and Mills (1982) observed that when lettuce, carrot (*Daucus carota* L.), and pea (*Pisum sativum* L.) crops were grown on sludge-amendment soils, small increases were observed in the Cu concentration and there was a considerable increase in Zn and Cd. Wong et al. (1983) pointed out that the content of Zn and Cu was highest in the root and shoot portions of plants grown on soil receiving activated sludge and compost treatment. They noted that Zn content of the aerial parts was also generally higher than that in the control. A higher amount of heavy metals was accumulated in the root portion than in the shoot portion of *Brassica* species.

Other field experiments have shown that, if sludges or sludge composts are low in metals, they can be used safely in the production of edible crops. Chaney and Giordano (1977) suggested that the maximum metal concentration in sludges should not exceed 2500, 1000, 200 and 25 $mg.kg^{-1}$ of Zn, Cu, Ni and Cd, respectively.

Although the heavy metal content of sludge determines the total sludge quantity that can be safely applied over the lifetime of a site, it is generally agreed that the N content dictates the annual rate of sludge application. Originally, most of the N in both soil and organic waste materials exists in organic form (Ryan et al., 1973; Epstein et al., 1978; Stark and Clapp, 1980), and must be mineralized before it becomes available to plants. Thus, the rate of mineralization is the key to the rate of application of any given organic material.

Mann and Barnes (1956) observed mineralization of 380 $g.kg^{-1}$ of organic C from digested sludge applied at an annual rate of 18.8 Mg/ha over a period of 9 years. Premi and Cornfield (1969) found that, at low sludge application rates (114 $kg.ha^{-1}$ of NH_4^+-N from sludge), rapid mineralization occurred. They also observed that with higher sludge application rates there was a lag phase before nitrification began. In their study, mineralization of the soil organic N was stimulated at the lower application rates compared to that at higher sludge rates. The same authors (1971) found that 230 to 420 $g.kg^{-1}$ of the organic N had mineralized after 6 weeks of incubation. Stanford and Smith (1972) pointed out that the rate of mineral N production in most soils also appears to depend on the amount of potentially mineralizable organic nitrogen in the soil. Amending a soil with sewage sludge may increase the amount of this N enough to change the rate of ammonification and, subsequently, the rate of net N mineralization in that soil.

King (1973) found that surface-applied sludge had mineralized 220 $g.kg^{-1}$ of the applied N in 18 weeks whereas incorporated sludge mineralized 380 $g.kg^{-1}$ of N in the same time. However, sludge applied on the soil surface resulted in 360 $g.kg^{-1}$ of N loss, but incorporation resulted in 220 $g.kg^{-1}$ of N loss in 18 weeks. Ryan et al. (1973) showed that 400 to 480 $g.kg^{-1}$ of organic N in anaerobically digested sludge had mineralized after 16 weeks of incubation. Pratt et al. (1973) suggested, for a given application of sludge to agricultural land in California, that 350, 100, 60, and 50 $g.kg^{-1}$ of the residual organic N are mineralized for the first, second, third, and fourth year, respectively, following application. However, Keeney et al. (1975) cited a decay series of 150 to 200, 60, 40, and 20 $g.kg^{-1}$ during a comparative time interval for Wisconsin conditions. When the concept of decay series was used, Pratt et al. (1973) and Keeney et al. (1975) estimated that the available N for each subsequent season is based on the amount of sludge C and N calculated to remain after preceding seasons. They ignored the effect of moisture and temperature on mineralization. These two factors can be adjusted for N mineralization rates and the details were given by Stanford and Smith (1972).

Magdof and Chromec (1977) found that from 140 to 250 $g.kg^{-1}$ of the organic N from anaerobically digested sludge in soil was mineralized during 13 weeks, whereas 360 to 620 $g.kg^{-1}$ of the organic N were mineralized from aerobically digested sludge. Mitchell et al. (1977) pointed out that aerobically digested sludge had a more diversified biota than anaerobically digested sewage sludge, and decomposed more quickly once it was added to soil. After an incubation period of 6 to 15 weeks, Epstein et al. (1978) reported that initially more active waste materials became stabilized and their decay and mineralization patterns became similar to those of initially more stable materials. They reported that 410 g $N.kg^{-1}$ of a digested sludge had mineralized after 15 weeks of incubation. Their initial decay and mineralization patterns differed radically between various kinds of wastes, which they concluded was primarily a function of the stability of the organic matter.

The concept of N mineralization potential (Stanford and Smith, 1972) was used by other researchers. Stark and Clapp (1980) found a high correlation between N mineralized during short periods and N mineralized during long periods of incubation, during which there was plant N uptake. They suggested that sludge application rates were more important than the sludge type in affecting N mineralization. Hsieh et al. (1981a; 1981b) reported that samples of activated sludge and anaerobically digested sludge had a similar behavior when applied to sandy soil and to unamended soil. From these data, the authors concluded that soil properties governed waste decomposition rate. Their data agreed with those of Stark and Clapp (1980) in that mineralization rates differed systematically with sludge rate. Furthermore, activated sludge mineralized at 150 to 200 g N.kg^{-1} faster than comparable rates of anaerobically digested sludge. Such trends indicated that different types of sludge mineralized at different but characteristic rates after incorporation into the soil.

Animal Manure

Animal manures, such as cow manure and poultry manure, should be recycled in the soil rather than merely discarded. Use of these two manure sources as soil amendments has been an acceptable way of disposal. Until recent years, insufficient manure was a greater problem than oversupply. Presently, concentration of dairy and poultry farms near large population centers and large numbers of beef animals in feedlots have created local manure surpluses.

Variation in composition of animal manures is the result of differences among species of animals, kinds and amounts of feeds consumed, and the management of manures following their production. Nitrogen content of poultry manure usually has been reported to be higher than beef and dairy cattle manure. Fresh manure from cattle have much higher N content than aged poultry manure. In comparison with chemical fertilizer, all are classified as low grade fertilizer as they supply relatively small quantities of plant nutrients per unit of dry weight. A safe statement that might be made about the composition of manures is that they have low concentrations of N, P and K as compared to commercial fertilizers. Manures also have traces to small amounts of most elements found in soils and plants. These metal concentrations may vary over considerable ranges (Pratt and Page, 1976).

In common with manufactured fertilizers, manures may have a high salt content. When applied at excessive amounts in the soil, the soluble salts content is increased and may either hinder plant growth or be washed into ground waters (Meek et al., 1974; Weil et al., 1979).

Decompositon begins soon after manure is incorporated into the soil. With large applications of manure, NO_3^--N concentration in the soil increases and may pollute surface or ground water. Various studies have resulted from concern about this aspect in soils receiving large amounts of manure (Olsen et al., 1970; Kimble et al., 1972; MacMillan et al., 1975; Bielby et al., 1973; Meek et al., 1974; Pratt et al., 1976). When soils are loaded with large amounts of manure, denitrification has been found to be a key mechanism in preventing or decreasing nitrate leaching beyond the root zone (Pratt et al., 1976). It was indicated that organic loading was more important than water management in creating O_2-deficient systems necessary for denitrification. Other investigations (Kimble et al., 1972; Meek et al., 1974; Guenzi et al., 1978) also reported denitrification when organic amendments were applied at high rates. They noted that when high concentration of organic materials was leached, NO_3^--N concentration in leachate also decreased at low redox potentials resulting from intensive microbial activity.

Studies in California (Meek et al., 1974; Adriano et al., 1971) and in Kansas (Wallingford et al., 1975) illustrated that manure application rates below 20 $Mg.ha^{-1}$ probably produce fairly low NO_3^--N concentration in soil and low concentration of leached organic material below the amended soil layer. They state that soluble salts are not necessarily a problem where manure is used at recommended rates in humid regions.

Cow Manure

Cow manure or farmyard manure is the most ancient of organic matter source used to conserve soil productivity. In England, field experiments on organic manures (Cooke et al., 1958) compared fertilizers and manure in long-term experiments. In the first half of the century, relatively low fertilizer rates were used. Today, as fertilizer doses have multiplied, crop yields are considerably higher. Williams and Cooke (1961) observed that stable soil structure was attained after use of manure, as well as under grass in clay soils. In the latter case, they reported that water permeability increased but, in sandy soils, the structure was not stabilized by using manure in the course of 18 years. Widdowson et al. (1982) discussed data from the fourth and fifth years of manure amendments of sandy silt loam soil at Woburn, England. They tested inorganic fertilizers with and without manure. Yields of all crops were largest where both manure and inorganic fertilizer were used and the effect of manure was not diminished by doubling fertilizer N. Cooke (1982) pointed out that about 28% of the agricultural land in England and Wales received organic manures, at rates of 25 $Mg.ha^{-1}$ in 1980.

In irrigated dark chestnut soil in the Southern Ukraine, Kiver and Kiver (1976) found that application of 30 to 40 $Mg.ha^{-1}$ of manure to vegetable crops and other crops in long-term experiments produced increased yields and the residual effects were noted for 5 to 6 years.

In Manitoba, Ridley and Hedlin (1968) reported that an application of barnyard manure at 8.9 $Mg.ha^{-1}$ to wheat maintained organic matter (77 $g.kg^{-1}$) at slightly higher levels than in unmanured plots (41 $g.kg^{-1}$). In studies conducted in Southern Alberta on dark brown Chernozen soil, Dubetz et al. (1975) applied manure at 27 $Mg.ha^{-1}$ every 4 years and 66 kg $N.ha^{-1}$ each year for 16 years to an irrigated crop rotation. They found that the application of manure increased the organic matter, and the N, P and K of the soil. Manure and manure plus N fertilizer increased yields of sugar beet (*Beta vulgaris* L.) and sweet corn (*Zea mays* L. var. sacchorata) but wheat yields were unaffected. Mathers and Stewart (1974) reported that application of 224 $Mg.ha^{-1}$ of manure for each of 3 years increased organic matter in the top 15 cm of soil from 15 to 30 $g.kg^{-1}$; however, Magdof and Amadon (1980), in a long-term experiment, found that 44 $Mg.ha^{-1}.year^{-1}$ was necessary to maintain soil organic matter levels during continuous corn (*Zea mays* L.) crops. Their highest yields were produced by combining 44 $Mg.ha^{-1}$ of manure and 224 kg $N.ha^{-1}$. In a 5-year study, also with continuous corn, conducted on a Typic Ochraqualf, McIntosh and Varney (1973) applied manures at rates from 0 to 66 $Mg.ha^{-1}$. They noted that cultivation and cropping of unmanured plots reduced organic N and C by 87 and 177 $Mg.ha^{-1}$ of soil, respectively. In their study, annual application of 44 $Mg.ha^{-1}$ of fresh dairy manure was required to maintain the soil organic matter level.

Long et al. (1975) pointed out that rates of dairy manure up to 45 $Mg.ha^{-1}$ may be spread safely in the southeastern United States.

Residual effect of dairy manure incorporated into two soils was studied by Zane and Doss (1980a) at rates of 0 to 270 $Mg.ha^{-1}$ after three annual applications. Residue from high application rates increased yield of corn, soil pH, soil concentration of K, Mg, P, and the cation exchange capacity of their soils. In another experiment, the same authors (1980b) applied dairy manure on the soil surface at solid rates of 45 and 90 $Mg.ha^{-1}.year^{-1}$ and as liquid at rates of 45, 90, and 135 $Mg.ha^{-1}.year^{-1}$ during 3 years. Additions of manures increased K, Mg, and pH in the subsoil, but downward movement of P was less than for other elements. Projection of the loss of organic N in the surface soil indicated that residual N would be negligible 45 to 55 months after applications ceased. Burl et al. (1982) observed that manure application to field plots for 9 years resulted in large losses of N, increased K levels, increased P availability, and also increased water intakes during the growing season. They observed that N mineralization rate was about 50 g $N.kg^{-1}$ after the first year.

Uptake of nutrients by crops can be increased when manures are used. Williams and Greig (1972) found that mineral fertilizers increased spinach (*Spinacia oleracea* L.) yield and concentration of N in the leaf tissue more than did organic fertilizers when nutrients were applied to make mineral and organic rates identical. They observed that organic fertilizer resulted in significantly higher P, Fe, and Na concentrations in the plant tissue than mineral fertilizer. However, Munro et al. (1978) reported that manure application had almost no effect on N concentration, and only small effect on P and K tissue of broccoli (Brassica oleracea var. italica) and brussels sprouts (Brassica oleracea var. gemmifera).

Poultry manure

A considerable portion of the total N in poultry manure is uric acid and during its decomposition in soil substantial amounts of NH_3 are released. This free NH_3 could have potential toxicity to plants (Siegel et al., 1975). It was observed that an incubation period should be allowed after application and before planting to enable nitrification of the NH_4^+-N to occur and plant uptake of NO_3^--N without risk of NH_3 toxicity (Eno, 1962).

Although the total amount of nutrients present in poultry manure is not immediately available, application at rates of several $Mg.ha^{-1}$ may supply sufficient N and P for most arable crops. However, if poultry manure is used, extra K may be necessary for potato (Solanum tuberosum L.), beet and other root crops (Cooke, 1982).

Field experiments conducted by Singh et al. (1970) demonstrated that yield and other growth features in cauliflower (Brassica oleraceo L. Botrytis) were significantly improved by increasing the level of poultry manure application from 0 to 17 $Mg.ha^{-1}$. They found that Ca and Mg in the curd were increased, although P and K contents were not influenced significantly by poultry manure application. Singh et al. (1973) pointed out that highest potato yield was obtained by addition of 80 kg $N.ha^{-1}$ from mineral fertilizer. In other studies with tomato (Lycopersicum esculetum. Mill) crop, yields increased with rate of poultry manure applied at rates from 0 to 8 $Mg.ha^{-1}$ when followed by a pre-plant application of a commercial 10-20-10 (N-P-K) fertilizer at 280 to 840 $kg.ha^{-1}$ (Morelock and Hall, 1980).

Poultry manure was also found beneficial for increasing strawberry (Fragaria spp.) yield (Hitz, 1951; Albregts and Howard, 1981). In their study, Albregts and Howard (1981) reported that soil organic matter content increased with manure rate and soil pH was only slightly affected by manure treatments. They noted that high rates of poultry manure (36 $\mathrm{mg.ha^{-1}}$) produced high levels of soluble salts and that foliage burn was noted during the first three seasons, which may have been the cause of reduced yields. Similar effects were observed by Shortall and Liebhardt (1975) in that excessive soluble salts were the primary cause of yield reduction in corn when high rates of poultry manure were applied.

Poultry manure, pig manure, activated sludge, and digested sludge were compared by Cheung and Wong (1983) for use as soil additives for growth of chinese cabbage (Brassica parachinensis). They found that animal manure resulted in better crop growth than sewage sludge. This was associated with higher productivity, earlier maturity, and absence of plant abnormalities.

Cowan (1976) conducted an experiment with grass (Lolium perenne) to evaluate the effect of poultry manure and inorganic (N-P-K) fertilizer together with the manure slurry. They found that poultry manure supplied levels of available N comparable with N levels from the fertilizer. Addition of poultry manure increased the amount of available Na, K, and Mg in the soil. However, Jackson et al. (1975) reported that land disposal of broiler litter greatly enhanced exchangeable K in the soil but the exchangeable Ca and Mg were reduced.

In laboratory studies, Reddy et al. (1980) observed transformations of N, P, and C in a Coastal Plain soil treated with beef manure, poultry manure, or swine manure. They observed that losses of NH_4^+-N from NH_3 volatilization were higher in the soil treated with poultry manure than in the soil treated with beef or swine manure. They reported that accumulation of NO_3^--N occurring in the soil treated with beef manures was nearly one-half that in the soil treated with poultry or swine manure. They concluded that animal manure application increased organic N, soluble P, and soluble organic C.

Jackson et al. (1977) found that, instead of increasing soil organic matter, applying high rates of poultry manure (134 $Mg.ha^{-1}.year^{-1}$) to the surface of a pasture decreased the soil organic matter content from 17 to 14 $g.kg^{-1}$ in the upper 10 cm. They explained this result by the 'priming effect' of leachate with low C:N which stimulated microbial activity and oxidation of the native soil organic matter.

After 5 years of heavy semi-annual applications of poultry manure in a clay loam soil, Weil and Kroontje (1979) observed that the overall ability of the soil to accept and dispose of the poultry manure did not appear to be seriously impaired even at higher rates of manure applications. They estimated that only 70 $g.kg^{-1}$ of organic matter from the 393 $Mg.ha^{-1}$ of the manure remained in the plow layer after 5 years.

Decomposition of Animal Manure

Although animal manures have been used for centuries as nutrient sources for plant growth, a rational basis for their use has not been developed. Application rates have been based on experience and little information has been available about decomposition rates and nutrient availability. At the present time, the rational method would be to determine the availability of N in the manure based on its properties, using a decay series (Pratt et al., 1973). The decay series concept was based on mineralization of organic N into inorganic or available N relative to the total N content of the manure. Poultry manure and cow manure would not necessarily have the same N mineralization rates even at the same total N content. Dry poultry manure that supplied 30 g $N.ha^{-1}$ would provide much more available N than that of fresh feedlot slurry manure that had 30 kg $N.ha^{-1}$ on a dry weight basis.

The decay series is a set of coefficients for the yearly mineralization of a given application of a manure. It is expressed as a series of fractional mineralizations of any given application, or as the residual of that application. Usually the rate of mineralization is most rapid the first year after application and will decrease in subsequent years. The decay series of 0.35, 0.15, 0.10, 0.05 implies that 350 g $N.kg^{-1}$ will be mineralized in the first year, 150, 100 and 50 $g.kg^{-1}$ of the residual N will be mineralized in the second, third, and fourth subsequent years, respectively. Pratt and coworkers (1973) also pointed out that, if a manure is higher in N content, it decays faster so that the decomposition patterns of manures differ, requiring development of several decay series. They stated that the decay series of 0.90, 0.10, 0.05 is typical of organic wastes such as poultry manure containing N, primarily present as rapidly mineralized urea or uric acid. These N materials are nearly as available as inorganic N sources. The decay series of 0.75, 0.15, 0.10, 0.05 represents materials in which about 500 $g.kg^{-1}$ of the N are present as urea or uric acid and the balance is slowly mineralizable organic compounds. Fresh wastes from dairy or beef cattle feedlots are also in this category.

Peat

The use of peat for agricultural purposes on mineral soils has increased at a rapid rate during the past few years. Most of this peat is utilized in vegetable gardens and greenhouses as an essential ingredient for use in potting mixtures or with soil for the growing of various potted plants.

According to Dyal (1960), more than half a million tons of peat were being sold annually in the United States, at that time, for soil improvement. Peat was often used previously as both a humus source and as fertilizer, with the expectation that it would give results similar to those obtained with animal manures. Although increased yields were often obtained, and the physical condition of the soil was improved, peat did not act like animal manures. This was due in part to deficiencies in mineral nutrients, but also to a greater extent to the comparatively inert nature of the material (Allison, 1973b). As already pointed out, manure is an active material and, as it decomposes, nutrients are constantly released through biological actions. In contrast, peat is so resistant to decomposition that much of the released nutrients must be retained by exchange reactions or as chelate elements. However, physical benefits derived from peat addition may be expected for several years after its application (Allison, 1973b).

Long-term effects of large additions of acid peat debris on the macro- and micromorphological properties of a nearly neutral silty clay loam topsoil were established by Collins and Coyle (1980). They noted changes through field morphological examinations and thin section observations. In their study, depth of peat added varied from 3 to 30 cm. These additions improved soil physical properties and faunal activity relative to the unamended topsoil. Additions of 5 to 8 cm caused acidification, structural alteration and Fe mobilization. Further additions, ranging up to 30 cm, caused progressive increase in acidification, structural collapse and fauna inactivity.

Peat, farm yard manure, peat compost, or peat plus manure mixture were applied at 6.3 $Mg.ha^{-1}$, in order to evaluate the yield and chemical composition of strawberry (Lucka et al., 1977). They found beneficial effects of treatments were observed only in the third year of their trials, and the highest total yields were obtained from plots with fertilizer in combination with peat-manure mixture. They reported no appreciable effect of any treatments on fruit chemical composition.

Johnston and Brookes (1978) reported results from an experiment made on sandy loam soil during 1963-1977 in England. They evaluated the effect of addition of peat in soil on many crops. They found that marketable production of bean, beet, and potato was increased by 300 $g.kg^{-1}$ or more. For carrot and other crops, the increase was 50 $g.kg^{-1}$ or less. Nitrogen fertilizers were often used most efficiently on soils with peat. Cumulative dry matter yields on soils with added peat were 100 $g.kg^{-1}$ greater than on untreated soil and this effect persisted even when peat application ceased.

Clay as an Amendment

The beneficial effects of adding silicates to highly-weathered soils whose silicon levels have been reduced by leaching are well established. A number of reasons have been proposed to explain these effects, such as the reduction of P sorption, the increase in soil pH, Ca supply, and cation exchange capacity (Uehara and Gillman, 1981).

Diamond and Fiskell (1965) and Fiskell and coworkers (1967) observed that suitable clay amounts can be incorporated into sandy soil in order to improve soil physical and chemical properties. They observed that soft rock phosphate may be beneficial to plant growth, especially when used at rates where the clay content may contribute significantly to moisture and nutrient retention.

The effect of the addition of bentonite clay and pond sediment (of varying N content) to a loamy sand was studied under different moisture regimens for the mineralization of N in these amendments (Aggarwal et al., 1980). They found higher mineralization of N occurred in soil treated with pond sediment, followed next by bentonite clay and the untreated soil, all at comparable moisture levels. They concluded that N mineralization potential and N mineralization rate of soil were increased when mixed with pond sediment and bentonite clay. In similar experiments, Gupta and Aggarwal (1980) observed that application up to 100 $g.kg^{-1}$ of bentonite clay or up to 250 $g.kg^{-1}$ of pond sediment to sandy loamy soil increased moisture retention at 0.01 and 1.5 M Pa tension as well as the available water capacity, total porosity, and percentage of clay aggregates > 0.25 mm. They reported that these clay amendments decreased the hydraulic conductivity and bulk density. They observed that bentonite was more effective than pond sediment in improving physical characteristics of soils, and that the total mineralized NH_4^+-N and NO_3^--N increased with the rate of addition of the amendments.

In field conditions on sandy soil, Lhotsky (1974) showed that bentonite influenced water reserve in the soil and reduced water seepage rate. The optimum rates of application were stated to be 1.27 to 2.54

$Mg.ha^{-1}$ where a 150 $g.kg^{-1}$ increase on crop yield occurred during a 7-year period.

The effect of bentonite on plant availability of sludge-borne heavy metals in soil was studied by Sims and Boswell (1978). Following the application of sludge, bentonite incorporation reduced the soil availability of some metals released from a sludge. They concluded that total plant content of Cd and Zn decreased in a linear manner as pH and cation exchange capacity increased as a result of the addition of bentonite.

Utilization of ^{15}N Tracer

Studies of the fate and residual effect of N from animal or sludge amendments in combination with inorganic N fertilizer are complicated by numerous N transformations occurring simultaneously in soil. Investigators are unable to distinguish N derived from the amendment from available soil N or fertilizer N after mixing and incubation.

Use of the ratio between stable N isotopes ^{14}N and ^{15}N in investigations of N transformations in plant and soil system has increased during the past decade in order to assist in defining how much of the total plant N uptake is derived from fertilizer N, or for leaching losses, and residual fertilizer N in the soil.

The first application of ^{15}N in agronomic research was by Norman and Werkman (1943) who used it to study uptake of N by soybeans (Glycine max L.). Since then more than 1500 papers related to the use of ^{15}N tracer techniques in agronomy have been published (Hauck and Bremner, 1976). The availability of ^{15}N-depleted or ^{15}N-enriched materials in substantial quantities has opened up the possibility of conducting field trials with labeled materials at moderate cost, while avoiding the disadvantages of microplots.

Advantages and disadvantages, analytical methodology, and uses of ^{15}N in soil research have been reviewed (Hauck and Bremner, 1976; Broadbent, 1981; Buresh et al., 1982).

Most previous studies on ^{15}N-labeled residual N forms have been conducted either in the greenhouse and laboratory experiments (Stewart et al., 1963; Broadbent and Nakashima, 1967; Stanford et al., 1970; Legg et al., 1971; Chichester et al., 1975). Relatively few studies with ^{15}N were conducted in the field. A review of field experiments with ^{15}N (Allison, 1964) indicated that most experiments gave low N recoveries in that the first crop normally removed from 400 to 500 $g.kg^{-1}$ of the fertilizer N. A subsequent crop increased the recovery to 760 to 880 $g.kg^{-1}$. In general, he stated that more N was accounted for in N-balance studies conducted in the greenhouse than was recovered in either lysimeter or field studies.

Pomares-Garcia and Pratt (1978) conducted a pot experiment with various rates of manure (0, 20, 40 and 50 $Mg.ha^{-1}$) and sludge (0, 10, 20 and 30 $Mg.ha^{-1}$) and combined these treatments factorially with 0, 50, 100, 150 and 200 Mg $N.kg^{-1}$ soil added as ammonium sulfate labeled with ^{15}N. They observed no significant effect of either organic amendments or of fertilizer rates on the overall N recovery by the crops. However, under manure treatments, the recoveries of fertilizer N by barley (Hordeum vulgare) forage were higher than those found with sludge. They point out that this effect was due to manure treatments rather than to the fertilizer. They observed that increasing rates of N from $(NH_4)_2SO_4$ increased the N available in the soil, whereas mixing with manure caused

N from $(NH_4)_2SO_4$ remaining almost constant. They obtained less N from the fertilizer when combined with sewage sludge treatments.

In a study of organic amendments, Caddy and Bartholomew (1960) concluded that the recovery of added tagged N was decreased by these amendments. They obtained an average of 80 $g.kg^{-1}$ of the tagged N taken up by the plant but 200 $g.kg^{-1}$ of this N were not recovered and were presumed to have been lost by denitrification and/or leaching.

Rolston (1978) and Rolston et al. (1979) reported on a field ^{15}N balance on uncropped plots that had received 300 kg $N.ha^{-1}$ as Ca $(^{15}NO_3)_2$ and which were maintained at two water levels (about 10^{-3} MPa and $6x10^{-3}$ MPa). The soil had received either 34 $Mg.ha^{-1}$ of manure or no manure as pretreatments. In the summer when soil temperature averaged 23°C, they showed that the plot receiving high water and manure had lost 720 to 780 $g.kg^{-1}$ of N, shown by ^{15}N analyses to be either N_2 or N_2O. They accounted for the remaining labeled N mainly through N leaching (about 130 $g.kg^{-1}$) and organic N forms (about 80 $g.kg^{-1}$). The other water treatment in combination with manure pretreatment lost 160 to 270 $g.kg^{-1}$ of the ^{15}N as N_2O plus N_2. They concluded that the remaining ^{15}N was predominantly in mineral form (about 530 $g.kg^{-1}$) and that about 21 $g.kg^{-1}$ occurred in organic N forms, and no leaching losses were observed.

Fertilizer ^{15}N incorporated into soil organic matter was not readily mineralized in experiments by Allen et al. (1973) and Broadbent (1980). In a further study, Broadbent and Nakashima (1967) showed that the number of days required for mineralization of 10 $g.kg^{-1}$ of the tagged N that had been incorporated in soil organic matter was increased with time following the fertilizer application.

Fiskell and Locascio (1983) conducted field experiments with mulched staked tomato utilizing ^{15}N-depleted ammonium sulfate and four other N sources under drip irrigation. They showed that the plant tops at the immature fruit stage contained nearly the same N content with the five N sources. They reported that, at this growth stage, 220 to 300 $g.kg^{-1}$ of the N in the tops was derived from fertilization. The remainder of the N originated from both preplant N and soil N. In the fruit harvested at 9, 11, and 13 weeks after initial fertilization, they observed recovery of 725, 629, and 488 $g.kg^{-1}$ of the N derived from fertilization, respectively.

Miller et al. (1981) used ^{15}N-depleted fertilizer as $(NH_4)_2SO_4$ to determine the percentage of tomato plant N derived from the applied fertilizer. Their data showed that higher fertilization rates resulted in a higher percent recovery of fertilizer N. They obtained less than 600 $g.kg^{-1}$ recovery of fertilizer N early in the season and approximately 300 $g.kg^{-1}$ by the end of the season.

Broadbent et al. (1980) also used ^{15}N-depleted $(NH_4)_2SO_4$, and found that recovery of fertilizer N by tomato plants ranged between 530 and 640 $g.kg^{-1}$ at all N rates (56, 112, 168, 224 $kg.ha^{-1}$). They also pointed out that more N in the tomato crop came from the soil than came from fertilizer N at all rates. At 112 kg $N.ha^{-1}$, the above-ground portions of the crop contained a total of 250 kg N/ha from an equivalent of 50 kg $N.mg^{-1}$ of dry matter produced, and only 13 kg $N.mg^{-1}$ of dry weight were obtained from the use of the applied fertilizer.

Differences in the abilities of crops to utilize fertilizer and soil N have been found to contribute to the establishment of rotation systems and to improve the efficiency of fertilizer use. Hills et al.

(1983) used ^{15}N-depleted $(NH_4)_2SO_4$ in a three-crop experiment (corn, sugarbeet and tomato) and unlabelled NH_4NO_3 in the two-crop experiment (corn, sugarbeet). They observed considerable site variability in the utilization of fertilizer N in individual crops. Their average recoveries of labeled N from fertilizer were 570 $g.kg^{-1}$ for corn, and 270 $g.kg^{-1}$ for tomato and sugarbeet when three-crop rotation was utilized. Similar N recoveries for the two crop rotation were 520 $g.kg^{-1}$ for corn and 370 $g.kg^{-1}$ for sugarbeet.

Crop Management Practices for Vegetable Crops

Improving crop management practices is an attempt to increase productivity. Research development of improved production technologies for each stage of vegetable crop production from tillage to harvesting has been achieved by varying levels of production inputs or introduction of new technologies.

Under Florida conditions, one successful technique for certain vegetables is utilization of polyethylene mulch (Locascio et al., 1960; Geraldson, 1962; Everett, 1971; Locascio et al., 1973; Locascio and Fiskell, 1977; 1979). Associated with this technique, increases in yield and uptake of nutrients by many vegetable crops have been achieved through drip-irrigation systems (Locascio and Myers, 1974; 1975; Locascio et al., 1982; Fiskell and Locascio, 1983).

When slow-release N fertilizer has been used in an attempt to match N requirements of crops with N available in the soil, substantial increases in yields have been achieved (Shelton, 1976; Locascio and Fiskell, 1979; Locascio et al., 1981). Further refinement in vegetable crops production through use of adequate fertilizer rates and placement are responsible for increased yields (Geraldson, 1962; 1963; Hayslip and Iley, 1964; Fiskell et al., 1967; 1977; Albregts, 1971; Navarro and Locascio, 1971; 1973; Persuad et al., 1976; Everett, 1976).

Bryan and Dalton (1974), Guilarte (1975), Csizinszky (1978), and Everett (1978) studied multiple cropping vegetable systems associated with residual fertilizer. They reported that by proper management of vegetable crops in Florida, such as tomato and pepper (_Capsicium annuun_ L.), it may be possible to double crop with either low or high management vegetables and field crops. Csizinszky (1978) observed that yields of carrot, green onion (_Allium cepa_ L.), lettuce and radish (_Raphanus sativum_ L.) were significantly higher in plots where no additional fertilizer was applied than in plots receiving fertilizer after tomato. He pointed out that the low yield in fertilized plots was due to high total soluble salts that reduced the seed germination of the second crop. Kretschmer et al. (1963) suggested that field corn is a good crop to follow fall tomato and other heavily fertilized vegetable crops on sandy soils in Florida. He reported that there was no need for additional P, K and micronutrients in order to produce a good corn yield.

Double cropping of a full-bed plastic mulch with other crops is practiced by many growers. The obvious advantage of multicropping on plastic mulched beds is reduction of energy use and production costs by permitting efficient use of both physical and applied resources (Bryan and Dalton, 1974). However, Everett (1978) observed that two factors can reduce the success of multicropping. These were insufficient residual fertilizer from the first crop and/or the effect of soil-borne plant disease and nematodes that build up during the first crop.

Everett (1978) also observed that, following Fall crops of tomato on plastic mulched beds, second crops could be planted either by seeding cucumber or by transplanting tomato. In his study, the two crops were planted as separate experiments where half the plot area was in cucumber and the other half in tomato. He found that the only significant increase in yield for both crops was between the check (no additional fertilizer) treatment and low fertilizer rate (70 kg $N.ha^{-1}$ with 100 kg $K.ha^{-1}$). He reported that, at fertilizer rates higher than the low rate, yields of tomato or cucumber did not differ statistically, regardless of placement methods.

Butternut squash produced high yields without additional fertilizer when planted after tomato grown under full-bed plastic mulch (Bryan and Dalton, 1974). In this study, higher yields of tomato and of the second crop of butternut squash resulted from complete and partial incorporation of fertilizer in beds under mulch than from banding all the fertilizer.

MATERIALS AND METHODS

Field experiments were conducted during the Spring and Fall seasons in 1982 and 1983 at the Horticultural Unit, University of Florida, Gainesville. The effects of organic amendments in combination with fertilizer were evaluated in 1982 on full-bed plastic mulch for staked tomato followed by slicer cucumber. This double cropping was continued also in 1983 using organic amendments and clay in combination with fertilizer. Rainfall distribution is shown in Fig. 1. Water stood between the beds during the period from 3/22 to 4/18 in 1982.

Selected properties of the amendments utilized in 1982 and 1983 experiments are presented in Table 1. In both years, newly cleared and limed soil was used. The soil was classified as Mulat fine sand (coarse to loamy, siliceous, hyperthermic Typic Ochraquults). Selected characteristics of this soil are shown in Appendix Tables 1 and 2.

Field Experiment in 1982

Tomato Experiment

Five amendments and two levels of fertilizer were evaluated. Treatments were combined in a 5x2 factorial arrangement in a randomized complete block design with four replications. Amendment sources were as follows: 1) 22.4 $Mg.ha^{-1}$ of sewage sludge from Largo, Florida, termed SS; 2) 22.4 $Mg.ha^{-1}$ of a mixture, termed PM, constituting of 17.9 $Mg.ha^{-1}$ of air-dried commercial source of poultry manure mixture with 4.5 $Mg.ha^{-1}$ of Florida peat to lower the pH of the amendment; 3) a second mixture, termed FP, consisting of 17.9 $Mg.ha^{-1}$ of Florida peat

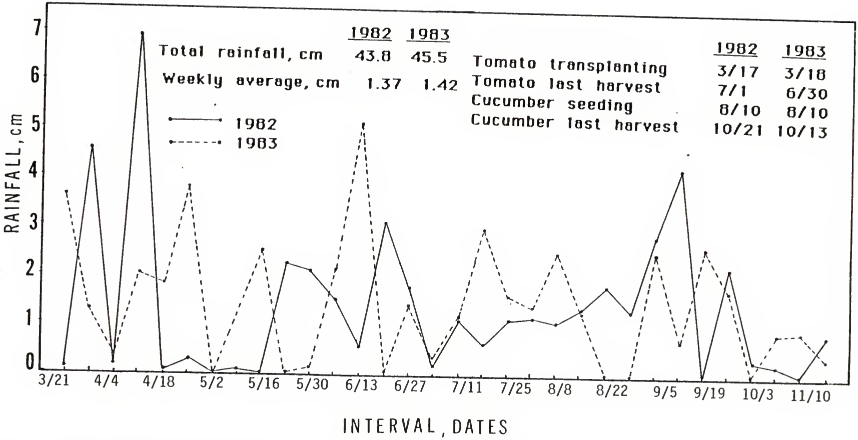

Fig. 1 Weekly rainfall distribution during the experimental periods for the 1982 and 1983 experiments.

Table 1. Selected properties of the amendments utilized in 1982 and 1983 experiments for vegetable crops.

Analysis	Sewage sludge^{+} 1982	Sewage sludge^{+} 1983	Poultry manure^{+} 1982	Poultry manure^{+} 1983	Florida peat^{+} 1982	Cow manure^{+} 1982	Bentonite clay^{++} 1983
pH (1:2)	5.80	5.40	8.10	7.33	4.10	5.32	-
EC*, dS.m^{-1}	5.16	4.92	8.20	8.25	1.10	1.60	-
Total C~, g.kg^{-1}	170	200	262	236	279	237	-
Total N^, g.kg^{-1}	50	45	39	38	12	16	-
K, g.kg^{-1}	5.8	3.3	28.2	25.9	0.5	9.2	0.4
P, g.kg^{-1}	31.5	29.2	14.2	15.1	0.4	2.8	-
Ca, g.kg^{-1}	14.3	13.6	0.8	1.0	0.3	1.2	10.4
Mg, g.kg^{-1}	4.9	4.3	3.5	3.9	0.4	0.5	0.1
Al, g.kg^{-1}	16.7	11.1	8.1	8.6	2.3	4.6	-
Fe, g.kg^{-1}	14.6	18.6	1.6	1.7	1.0	2.0	-
Mn, mg.kg^{-1}	280.1	480.0	206	193	25	34	-
Cu, mg.kg^{-1}	410.0	970.0	93	78	6	17	-
Cd, mg.kg^{-1}	12	55	0.1	0.1	0.1	0.1	-
Ni, mg.kg^{-1}	48	80	16	13	7	1.00	-
Cr, mg.kg^{-1}	150	1834	9	9	8	8	-

$^{+}$Wet digested with 16 M HNO_3 and 12 M $HClO_4$

$^{++}$$NH_4NO_3$ extract (1:1)

*Electrical conductivity (1:1)

~Leco-Induction furnace

^Micro-Kjeldalhl

mixed with 4.5 $Mg.ha^{-1}$ poultry manure to raise the amendment pH; 4) anaerobically digested cow manure termed CM; 5) fertilizer only, termed FO. The N, P, and K supplied were equivalent to that provided in 1400 and 2800 $kg.ha^{-1}$ of a 6-3.5-6.6 (N, P, K) commercial fertilizer. These two fertilizer rates are therefore termed 1400 and 2800 $kg.ha^{-1}$ in the text. The N source was ^{15}N-depleted ammonium sulfate (21% N) obtained from the Tennessee Valley Authority; P was derived from ordinary superphosphate (8.7% P); K as muriate of potash (49.9% K), and micronutrients as frit (FTE 503). Each treatment (except for the fertilizer only treatment) was blended in a cement mixer and water was added to near that of mixture saturation. The amendments and fertilizer were weighed on the air dry matter basis for each plot, which was 11 m long and 1.22 m wide. All amendments and fertilizer were applied broadcast on March 11 and incorporated by a rotatiller into beds which were formed by a bed press. The amended soil was covered by 0.025 mm thick black polyethylene mulch.

Containerized tomato plants, cultivar Sunny, were approximately 15 cm tall when transplanted at 45 cm spacing on March 18. Tomato plants were pruned and grown on twine and stakes. An overhead irrigation system was utilized. Fruit yield were taken from 22 plants of each plot. Fruit harvests were on June 10, June 17, June 24, and July 1, 1982. Fruit fresh weight was obtained after grading into four size categories. The mean fruit weights for the four fruit sizes were 205, 150, 115, and 85 g. Marketable yield was the sum of yields of all size categories.

Approximately 15 days after the last tomato harvest, the old tomato vines were cut just above the soil line and removed from the beds with a minimum amount of damage to the plastic mulch.

Cucumber Experiment

On August 10, cucumber seeds, cultivar Poinsett, were planted in the original undisturbed plots without additional fertilizer. A single row in the bed center was used and seedlings were thinned to a single plant at every 30 cm of row. Two weeks after germination, the last plant at the plot boundary was removed. Fruit yields were taken from 34 plants from each plot. Fruit harvest began 55 days after seeding and was conducted at 6- to 7-day intervals for a total of four harvests. The yields obtained in the first two harvests were considered as early yield.

Field Experiments in 1983

Tomato Experiment

Four amendments were used: 1) sewage sludge from Orlando, Florida, termed SS; 2) air-dried commercial source of poultry manure, termed PM; 3) dry bentonite clay (American Colloid Company), termed BC; and 4) fertilizer only, termed FO. The amendments rates were 11.2 and 22.4 $Mg.ha^{-1}$ for sewage sludge and poultry manure. Rates of 1.12 and 2.24 $Mg.ha^{-1}$ were used for the bentonite clay.

The commercial fertilizer mixture employed was 6-3.5-6.6 as N-P-K plus micronutrients which was derived from ammonium nitrate, diammonium phosphate, muriate of potash and frit (FTE-503). Rates of 0, 1400, and 2800 $kg.ha^{-1}$ were applied on plots receiving sewage sludge or poultry manure. Plots without these amendments, and those with added bentonite clay were supplemented with 1400, 2800, and 4200 kg.ha^{-1} of the above fertilizer.

Amendment sources, rates, and fertilizer levels were arranged in a semi-complete factorial in a randomized complete block design with three replications for a total of 21 treatments.

All treatments were applied broadcast on March 4 and incorporated into the beds' centers by a rotatiller and bed press.

Containerized tomato plants, cultivar Sunny, were transplanted at 45 cm spacing on March 17. Plot size, fruit grades, and culturals practices were conducted as for the 1982 field experiment. Fruit harvest was made on June 16, June 23, and June 30.

Cucumber Experiment

Approximately 15 days after the last tomato harvest, tomato vines, twines, and stakes were removed. The original plot size utilized in the tomato experiment was divided in half. Cucumber cultivar 'Poinsett' was seeded on August 10. One-half of each plot received no further fertilizer. The other half received liquid fertilization as 40-0-33 kg.ha^{-1}, where the N and K were supplied as ammonium nitrate (33.5% N) and muriate of potash (49.9% K), respectively, at 15 days after seeding. This supplemental fertilizer was applied to the soil at 20 cm depth in 25 ml of solution between plants, using a manual injector.

Fruit harvests began 50 days after seeding and were made at 3- to 4-day intervals. A total of six harvests were made. Yield obtained in the first three harvests was considered as early yield.

Laboratory Experiments

In order to evaluate the microbial activity for each treatment used in the 1982 and 1983 experiments, CO_2 evolution over time was measured. Soil samples from the 1982 experiment were taken 7 days after application of the amendments. These samples were air-dried and passed through a 2 mm sieve and 50 g weighed into 250-ml Enlenmeyer flasks. Two replications for each treatment were used. The moisture content was adjusted to approximately -33 kPa soil moisture potential.

In the 1983 experiment, soil samples were not air-dried and the field moisture content was not adjusted. Soil samples were taken 19 days after application of the treatments. Samples at field moisture were passed through a 2 mm seive and 50 g weighed into 250 ml Enlenmeyer flasks. Two replications for each treatment were used.

An additional set of soil samples was weighed into tared paper bags and the moisture content determined after oven-drying for 72 h at 100°C. The flasks containing the soil samples were connected to a closed system constantly aerated with CO_2-free moist air. The CO_2 evolved from each treatment was collected in 0.0998 M NaOH contained in 100-ml tubes. The CO_2 was determined after 3, 6, 13, 20, 27, 41 and 60 days in 1982 and 3, 10, 17, 24, 31, 38, 60 days in 1983. Each determination was made by titration with 0.1078 M HCl using phenolphthalein as indicator.

Analytical Methods

Soil Analysis

A series of soil samples (0 to 20 cm) was taken prior to applying treatments on February 20, 1982 and March 2, 1983. Selected chemical analysis for these samples are shown in Appendix Table 2.

In 1982, core samples were taken to a 20 cm depth on each plot on March 18, April 20, May 5, and June 29 in the tomato and on August 20 in the cucumber treatments.

In 1983, core samples of each plot were taken on March 23, April 21, May 23, and June 23 from the tomato and on August 13 from the cucumber treatments.

Determinations of cation exchange capacity (CEC) and organic C were made for seived air-dried soil. For all other soil determinations, fresh soil samples were used at the field moisture level. An additional portion of each soil sample was taken for moisture content determination so that analysis could be expressed on the dry soil basis.

A 50-g sample of fresh soil was mixed with 50 ml of deionized water and allowed to stand for 20 minutes. After stirring, soil pH was determined by an Orion Model 710 digital pH/mV meter and combination glass electrode. The solution was filtered through a 0.45 µ membrane filter (Nalge) using a vacuum pump assembly. Electrical conductivity was measured with a 1-cm conductivity cell and sensitive ohm meter (Barnstead Model, PM-70CB) and data were calculated to $dS.m^{-1}$ ($mmho.cm^{-1}$) in the soil solution at field moisture content. Chloride levels in the filtrates were determined with a specific ion electrode (Orion Model 93-17) and NO_3^--N by a nitrate electrode (Orion Model 90-02). The NH_4^+-N concentration was determined by the phenate method by a modification of the Technicon procedure (EPA, 1968) and the color read by a spectrophotometer (Spectronic 21) at 659 nm. If samples had NH_4^+-N concentrations above that of the top standard of 14 $mg.L^{-1}$ of NH_4^+-N, a 1 or 2 ml aliquot (usually sufficient) was diluted to 50 ml and a suitable aliquot taken within the standard range.

Concentrations of Ca, Mg, Fe, Mn, Zn, Cu, Ni, and Cd were determined in water extract by atomic absorption and K by flame emission photometry. Concentration of P was determined by Technicon Auto

Analyser II using the ascorbic acid-molybdate blue complex read at 880 nm (EPA, 1968).

Potassium chloride extracts for 1982 and 1983 soil samples were obtained following addition of 50 ml of 1 M KCl to 50 g of soil, and then filtered as given above for water extracts. In 1982, the soil samples utilized were the same as those extracted previously for water extracts. In 1983, extracts were obtained in separate 50-g samples of soils. The extracts were transferred to plastic vials, capped, and stored at 4°C. An aliquot of 15 ml was pipetted into a steam distillation apparatus and approximately 0.25 g of MgO was added. The NH_4^+-N was distilled into 5 ml of boric acid mixed indicator solution in a 50 ml Erlenmeyer flask. The distillate volume was about 35 ml, the NH_4^+-N concentration was determined by titration with 0.0054 M sulfuric acid (Bremner, 1965).

The double acid extract (0.05 M HCl + 0.013 M H_2SO_4), now called Mehlich I extract, was utilized in 1983. A 20-g sample of fresh soil taken in the tomato or cucumber experiments was shaken with 80 ml of Mehlich I extract for 20 min on a reciprocating shaker and filtered through 0.45 μ membrane filter (Nalge) using a vacuum pump assembly. The filtrate was saved and concentrations of Al, Ca, Cd, Cu, Fe, Mg, Mn, Ni, and Zn were determined by atomic absorption. Potassium was analyzed by flame emission photometry and the phenate method was used for NH_4^+-N.

Organic matter and cation exchange capacity (CEC) were determined on soil samples taken at March 18, May 20, and August 9 in 1982, and at March 23, May 21, and August 9 in 1983. Treatments that received fertilizer at a rate 2800 $kg.ha^{-1}$ were selected in 1982. In 1983, treatments that received either only amendments or treatments that received fertilizer at rate 2800 $kg.ha^{-1}$ were selected for analysis.

Organic matter was determined by the Walkley-Black oxidation method (Allison, 1965) except that the end-point was found by redox titration with an indicating Pt electrode and a gel-filled polymer body with a reference calomel electrode.

Cation exchange capacity (CEC) was determined using a procedure followed by Fiskell and Zelazny (1971). Soil samples were air-dried and screened through a 2-mm mesh seive. A 10-g sample of soil was weighed into 100-ml polyethylene centrifuge tubes and 50 ml of 0.5 $\underline{M}$ $CaCl_2$ were added. Samples were stirred before centrifuging. The solution was discarded and the process repeated twice with 0.05 $\underline{M}$ $CaCl_2$. The samples then were stirred with 30 ml of methanol and centrifuged. This step was repeated and the solution discarded. Displacement of Ca was accomplished with 50 ml of 1 $\underline{M}$ NH_4NO_3 followed twice by 25 ml additions, stirring and centrifuging operations. Volume of the combined solution was brought to 100 ml, shaken, and Ca analyzed by atomic absorption. Test for residual Cl was measured by a specific Cl ion electrode using Cl standards made in 1 $\underline{M}$ NH_4NO_3. The solution pH was determined and cation exchange capacity was calculated from mmol $(\frac{1}{2}Ca^{2+}).kg^{-1}$ minus residual mmol $(\frac{1}{2}Ca^{2+}).kg^{-1}$ determined as one-half the mmol $(Cl^-).kg^{-1}$ present.

Tissue Analysis

In 1982, leaf samples were taken on April 28, May 20, June 19 and fruit samples taken on May 20, June 11 and July 2 from the tomato plants. Cucumber leaf and fruit samples were taken on September 19 and October 13, respectively.

In 1983 tomato leaf samples (recently mature, fully expanded leaves) were taken on April 28, May 20, June 19 and fruit samples were taken on June 16. Cucumber leaf samples were taken on September 2 and September 27 and fruit samples were obtained on October 10.

Samples were collected and dried in a forced-air dryer at 70°C, ground with a Wiley mill to pass through a 1.27 mm mesh stainless steel seive, and stored in air-tight glass bottles.

Total N was determined by the Kjeldahl method (Nelson and Sommers, 1973) on a 0.25 g sample after digesting with 5 ml of H_2SO_4 with salicylic acid, 0.5 g of Cu catalyst, and 0.4 g sodium thiosulfate. Digested samples were transferred to a distillation flask, 20 ml of 10 $\underline{M}$ NaOH were added and NH_3-N in the distillate was collected in 5 ml of boric acid containing a mixed indicator. The distillate was titrated with 0.0054 $\underline{M}$ H_2SO_4 to a purple-pink end-point.

Samples for mineral analysis were prepared using a 1-g sample of dry plant tissue and digested with 5 ml of concentrated HNO_3 in 100-ml test tubes covered by a glass refluxing cap. The digestion was continued at 80°C for an hour after the solution had cleared. The temperature was increased, and the solution was evaporated to near dryness. The sample was brought to 25 ml with deionized water, shaken, and stored in vials. The solution was analyzed for Al, Ca, Mg, Fe, Mn, Zn, Cu, Ni, and Cd as stated for the water extracts.

Five tomato or cucumber fruits were sampled from each treatment plot yield in both the 1982 and 1983 experiments. The samples were washed with deionized water, blended, frozen, and freeze-dried. Fruit samples for mineral analysis were prepared and analyzed as described previously for leaf samples.

Tracer ^{15}N Analysis

In 1982, ^{15}N-depleted $(NH_4)_2SO_4$ was the N source utilized. All soil, leaf and fruit samples taken on tomato and cucumber experiments in 1982 were analyzed for labeled N.

After the NH_4^+-N concentration in the sample was determined by titration as described above, the distillate from steam distillation was slightly acidifed with 1 ml of 0.12 M H_2SO_4 to prevent NH_4-N loss and evaporated on a hot plate to reduce the volume from 3 to 5 ml. Isotopic N ratio analysis were made (Micromass Spectrometer Model 620 E) at the Soil Science Department, University of Florida.

The amount of labeled fertilizer N derived from ^{15}N-depleted $(NH_4)_2SO_4$ was calculated from the equation

$$X = \frac{b-c}{b-a} \times 100 \qquad [1]$$

where X = % ^{15}N from fertilizer in the soil, leaf, and fruit samples, a = fertilizer atom % ^{15}N (0.00615), b = standard atom % ^{15}N (0.3665), and c = sample atom % ^{15}N.

Statistical Analysis

Statistical analysis were processed by SAS computer procedures, through the general linear model procedure (Helwig and Council, 1979) at the Northeast Regional Data Center of the University of Florida.

In the 1982 tomato and cucumber experiments, analysis of variance was for a 5x2 factorial arranged in a randomized complete block design with four replications. Means were compared by the Duncan's Multiple Range Test.

In the 1983 tomato experiment, the treatment factors of amendment sources, amendment rate, and fertilizer levels were arranged in a semi-complete factorial in a randomized complete block design with three replications. These factors were considered as 21 treatments. In the first analysis, the 20 degrees of freedom were broken down into 20 orthogonal contrasts. The contrast abbreviations and the corresponding responses studied are shown in Table 2.

In a second analysis, seven treatments were selected in order to compare amendment sources at two fertilizer levels. The seven treatments were 1) Sewage sludge at 11.2 $Mg.ha^{-1}$; 2) Sewage sludge at 22.4 $Mg.ha^{-1}$; 3) Poultry manure at 11.2 $Mg.ha^{-1}$; 4) Poultry manure at 22.4 $Mg.ha^{-1}$; 5) Bentonite clay at 1.12 $Mg.ha^{-1}$; 6) Bentonite clay at 2.24 $Mg.ha^{-1}$ and7) fertilizer only. The two fertilizer levels were 1400 and 2800 $kg.ha^{-1}$ as described previously for this tomato experiment. Analysis of variance was conducted for a 7x2 factorial arranged in a randomized complete block design with three replications and means were compared by the Duncan's Multiple Range Test.

In the 1983 cucumber experiment, two different statistical analysis were utilized. For the first one, analysis of variance for the split-plot design was utilized, considering the main plots as the original 21 treatments applied for the tomato crop and the sub-plots as supplemental NK fertilizer (one-half of original plots received no additional NK application). The same contrasts defined above for the tomato experiment presented in Table 2 were considered.

A second type of analysis was conducted with the same seven treatments mentioned previously with the two fertilizer levels as defined above for tomato. These seven treatments were considered with

Table 2. Contrast abbreviations and contrast responses for tomato and cucumber experiments, 1983.

Constrast abbreviations	Contrast response
	Fertilizer responses
FO-L	Linear effect, fertilizer alone
FO-Q	Quadratic effect, fertilizer alone
	Sewage sludge responses
SS-R	Sewage sludge, rate 1 vs rate 2
SS-FL	Linear main effect of fertilizer within sewage sludge
SS-FQ	Quadratic main effect of fertilizer within sewage sludge
SS-RxFL	Interaction of sewage sludge rate with linear fertilizer effect
SS-RxFQ	Interaction of sewage sludge rate with quadratic fertilizer effect
	Poultry manure responses
PM-R	Poultry manure, rate 1 vs rate 2
PM-FL	Linear main effect of fertilizer within poultry manure
PM-FQ	Quadratic main effect of fertilizer within poultry manure
PM-RxFL	Interaction of poultry manure rate with linear fertilizer effect
PM-RxFQ	Interaction of poultry manure rate with quadratic fertilizer effect
	Bentonite clay responses
BC-R	Bentonite clay, rate 1 vs rate 2
BC-FL	Linear main effect of fertilizer within bentonite clay
BC-FQ	Quadratic main effect of fertilizer within bentonite clay
BC-RxFL	Interaction of bentonite clay rate with linear fertilizer effect
BC-RxFQ	Interaction of bentonite clay rate with quadratic fertilizer effect
	Amendment comparisons
FO vs BC	Means of fertilizer only vs means of bentonite clay
SS vs PM	Means of sewage sludge vs means of poultry manure
OA vs IA	Means of organic amendments vs means of organic amendments

or without NK application. In this case, a 7x2 factorial combination was considered as main plot and supplemental NK application as subplot. Means were compared by the Duncan's Multiple Range Test.

In both 1982 and 1983 experiments, a complete randomized design was utilized to compare treatment effects on soil organic matter, cation exchange capacity and carbon dioxide evolution. Means were compared by the Duncan's Multiple Range Test.

RESULTS

Tomato Experiment. Spring, 1982

Tomato Fruit Yield

On soil amended with SS and PM, tomato plants had more vigor during all the crop season than for the other three amendments.

Tomato yield in the first fruit size category was not statistically different among amendment sources. However, when PM was used, fruit yield was 43% more than for FO (Table 3).

In the second fruit size category, tomato plants on SS and PM produced the highest fruit yield and these were significantly different from that for FO. Increases of 11 and 12.7 $Mg.ha^{-1}$ in fruit yield were found for these two amendments, respectively. Among the four organic amendment sources, no significant differences were observed (Table 3).

In the third fruit size category, the fruit yield with SS was 75% more than yield for FO. Yields from the SS and PM amendments did not differ in this fruit size category. However, this size of fruit yield grown on SS was statistically greater than from the other three amendment sources (Table 3).

Yield in the smallest size category was not statistically affected by amendment sources or fertilizer levels.

Total yields ranged from 69.5 to 99.7 $Mg.ha^{-1}$. The highest yield was obtained with the PM amendment. The lowest yield was observed when FO was used (Table 3).

Table 3. Analysis of variance and main effect of amendment and fertilizer levels on tomato fruit yield. Tomato experiment, 1982.

Source of variation	df	Fruit yield				
		Size categories[+]				
		1	2	3	4	Total
		Mean square				
Blocks	3	1462.35***	689.95***	116.81	3.01	3786.11***
Amendment (A)	4	204.52	193.47*	134.05*	2.60	1036.13*
Fertilizer level (F)	1	46.23	155.91	29.60	0.23	636.31
AxF	4	22.24	73.07	11.55	1.06	188.36
Error	27	149.27	68.00	40.66	1.63	345.77
		Fruit yield (Mg.ha^{-1})				
Amendment[‡]						
SS		24.3	38.4a[y]	23.8a	3.5	90.0a
PM		37.2	40.1a	18.9ab	3.5	99.7a
FP		29.9	34.4ab	16.0b	2.9	81.1ab
CM		27.3	33.2ab	14.5b	2.4	79.6ab
FO		26.0	27.4b	13.6b	2.3	69.5b
F value		NS	*	*	NS	*
Fertilizer level (kg.ha^{-1})						
1400		27.9	32.7	16.5	2.85	79.9
2800		30.0	36.6	18.2	3.01	87.8
F value		NS	NS	NS	NS	NS

[+] Mean fruit weight were as follows: 1) 250 g, 2) 150 g, 3) 115 g and 4) 85 g.

NS, *, ***F value not significant, significant at the 5% and 0.1% levels, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

[‡] SS=22.4 Mg.ha^{-1} of sewage sludge from Largo, Florida, PM = 22.4 Mg.ha^{-1} of mixture consisting of 17.9 Mg.ha^{-1} of poultry manure plus 4.5 Mg.ha^{-1} of Florida peat, FP=22.4 Mg.ha^{-1} of mixture consisting of 17.9 Mg.ha^{-1} of Florida peat plus 4.5 Mg.ha^{-1} of poultry manure, CM=22.4 Mg.ha^{-1} of anaerobically digested cow manure and FO is fertilizer only.

Total yield was influenced in a similar fashion to that found for the fruit in the second size category. The correlation coefficients (Pearson product-moment) between total yield and size categories 1, 2, 3, and 4 were 0.79, 0.91, 0.39, and 0.24, respectively. The first two coefficients were statistically significant at the 0.1% level and the third at the 5% level while the last one was not statistically significant.

Among the four organic amendments used, no statistically significant differences were observed in regard to total fruit yield. However, use of these amendments resulted in an increase of 43%, 29%, 17%, and 14% for total yield for PM, SS, FP, and CM, respectively, over that for FO.

Total fruit yield and yield in all sizes categories increased when the level of fertilizer was increased from 1400 to 2800 $kg.ha^{-1}$. However, no significant difference was detected between fertilizer levels for all size categories and total yield.

Soil Analysis

Nitrogen Availability

Amendment source and fertilizer level both affected the forms of soil N extracted at four dates after application of treatments (Table A-3).

Main effects of amendment sources and fertilizer levels were statistically significant for all forms of soil N extracted at all sampling dates. Interaction between these two factors was significant at 7 days for NH_4^+-N in water, NH_4^+-N in 1 M KCl, and available total N. Also, interaction was significant at 70 and 110 days for NO_3^--N (Table

A-3). Main effect for amendments and fertilizer levels was considered when interaction effect was not significant.

Nitrate level in soil sampled during the growing season was highest at 40 days after application of treatments. This was observed for all amendment sources except for sewage sludge, in which case the highest nitrification occurred in samples taken at 70 days.

At 7 days, the main effect for SS differed statistically from that of the other amendment sources and generated 13, 14, 14, and 24 $mg.kg^{-1}$ more NO_3^--N than did the PM, FP, CM, and FO amendments, respectively.

At 40 days, PM was statistically different for NO_3^--N from the other four amendment sources and generated 1.6 and 2.0 times more NO_3^--N than that found for the average of the three organic sources and FO, respectively.

Ammonium N in water extract and exchangeable NH_4^+-N concentration decreased from 7 to 110 days after application of treatments for all amendment sources. Decreases of 94, 87, 93, 89, and 93% for NH_4^+-N in water and 91, 93, 91, 88, and 90% for exchangeable NH_4^+-N from 7 to 110 days were observed with SS, PM, FP, CM, and FO amendments, respectively (Table 4). At all sampling dates, SS and PM gave the highest NH_4^+-N in water and exchangeable NH_4^+-N concentrations and these values were significantly different from the other three amendments (Table 4).

Available total N also decreased from 7 to 110 days for all amendment sources. Decreases of 83, 89, 91, 88, and 89% from 7 to 110 days were observed with SS, PM, FP, CM, and FO amendments, respectively.

The average of the available total N among all organic amendments compared with FO, generated 135, 60, 123, and 80% more available N at 7, 40, 70, and 110 days after application of treatments, respectively.

Table 4. Main effect of amendment and fertilizer levels on forms of soil N extracted at four dates after application of treatments. Tomato experiment, 1982.

Treatment	Soil N extracted							
	Water extract		KCl extract	Available total N	Water extract		KCl extract	Available total N
	NO_3^--N	NH_4^+-N	NH_4^+-N		NO_3^--N	NH_4^+-N	NH_4^+-N	
	------------------------------------ mg.kg^{-1}	------------------------------------						
Amendment$^+$	7 days after application of treatments				40 days after application of treatments			
SS	53a^y	248^z	216^z	517^z	82b	40a	93a	215a
PM	40b	214	248	502	102a	18b	41b	161b
FP	39b	116	113	268	53c	13c	27c	93c
CM	39b	56	67	162	54c	12c	17c	83c
FO	29c	61	64	154	50c	13c	23c	86c
F value	***	***	***	***	***	***	***	***
Fert. level (kg.ha^{-1})								
1400	37	113	116	265	65	17	37	119
2800	42	166	169	377	72	21	44	137
F value	**	***	***	***	**	**	**	***
Amendment$^+$	70 days after application of treatments				110 days after application of treatments			
SS	164^z	21a	27a	212a	52^z	14a	19a	85a
PM	67	11b	17b	95b	26	11b	15b	52b
FP	28	8c	18b	54c	8	5c	10c	23c
CM	26	6c	11c	41c	6	5c	8d	19c
FO	25	8c	10c	45c	6	4c	6e	16c
F value	***	***	**	***	***	***	***	***
Fert. level (kg.ha^{-1})								
1400	55	9	16	80	18	6	10	34
2800	69	13	20	102	22	8	13	43
F value	***	***	**	***	**	***	***	*

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test.

[z] Significant interaction between amendment and fertilizer levels.

[+] See Table 3 for abbreviations.

Highest available total N concentrations were maintained with SS and PM during the crop season. These two treatments were significantly different from the other three amendment sources throughout the season.

Statistical difference for main effect of fertilizer was found, at all four dates, for NO_3^--N, NH_4^+-N in water, exchangeable NH_4^+-N and available total N concentration (Table A-3). As expected, the higher level of fertilizer generated higher concentration of all forms of soil N extracted at all soil sampling dates (Table 4).

Interaction means between amendment source and fertilizer level are presented in Table 5. At 7 days for both fertilizer levels, NH_4^+-N in water, exchangeable NH_4^+-N and available total N concentration were highest with SS and PM amendments. These two amendment sources were significantly different from the other three amendment sources. At a fertilizer level of 1400 $kg.ha^{-1}$, SS and PM were significantly different from each other in regard to NH_4^+-N in water and available total N. However, at the level of 2800 $kg.ha^{-1}$, these values were not significantly different.

At 70 and 110 days, SS amendment at both fertilizer levels generated significantly more NO_3^--N concentration than the other four amendments. Nitrate-N concentration generated by PM was significantly different from that of FP, CM and FO at both rates and all sampling dates. No statistically significant difference among FM, CM and FO was observed for NO_3^--N concentration at both sampling dates and fertilizer levels (Table 5).

Percentages of exchangeable NH_4^+-N coming from fertilizer at 7 and 40 days after application of treatments were estimated using ^{15}N-depleted tracer fertilizer and are shown in Fig. 2.

Table 5. Interaction means between amendment and fertilizer levels on forms of soil N extracted at 7, 70 and 110 days after application of treatments. Tomato experiment, 1982.

Amendment[+]	Fertilizer level (kg.ha^{-1})									
	1400	2800	1400	2800	1400	2800	1400	2800	1400	2800
	mg.kg^{-1}									
	7 days^						70 days^		110 days^	
	NH_4^+-N, water		NH_4^+-N, KCl		Available total N		NO_3^--N, water			
SS	224a[y]	273a	191a	241a	464a	154a	573a	46a	175a	58a
PM	161b	268a	211a	286a	406b	57b	590a	21b	77b	31b
FP	73c	160b	55c	172b	162c	28c	377b	8c	29c	8c
CM	55c	58c	62c	72c	152c	19c	172b	6c	31c	7c
FO	52c	71c	59c	69c	138c	17c	171c	6c	34c	7c

[y] Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

^Days after application of treatments.

[+] See Table 3 for abbreviations.

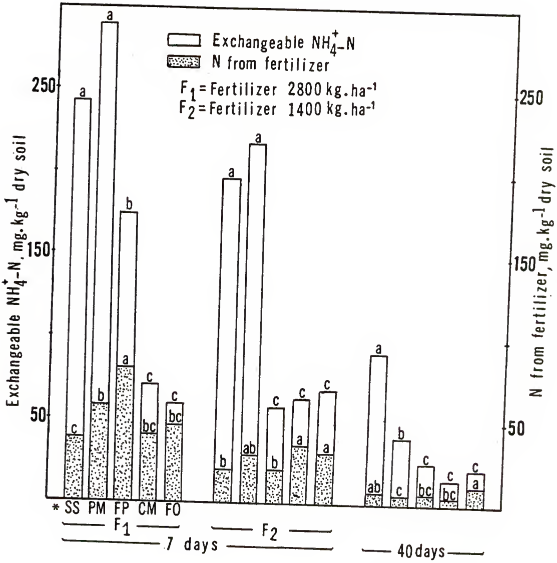

Fig. 2. Interaction and main effect of amendment and fertilizer level on exchangeable NH_4^+-N and N from fertilizer at two dates after application of treatments. Tomato experiment, 1982. (Mean separation between amendments by Duncan's Multiple Range Test, 5% level).
*SS=22.4 Mg.ha^{-1} of sewage sludge from Largo, Florida, PM=22.4 Mg.ha^{-1} of mixture consisting of 17.9 Mg.ha^{-1} of poultry manure plus 4.5 Mg.ha^{-1} of Florida peat, FP=22.4 Mg.ha^{-1} of mixture consisting of 17.9 Mg.ha^{-1} of Florida peat plus 4.5 Mg.ha^{-1} of poultry manure, CM=22.4 Mg.ha^{-1} of anaeorbic digested cow manure and FO is fertilizer only. The sequence of amendments at 7 days for F_2 and at 40 days is the same as that at 7 days for F_1.

At 7 days, the interaction for NH_4^+-N between amendment sources and fertilizer levels was statistically significant (Table A-3). When fertilizer was applied at 2800 kg.ha^{-1}, the percentage of exchangeable NH_4^+-N coming from fertilizer with SS, PM, FP, CM, and FO was 15, 20, 46, 57, and 67%, respectively. At the fertilizer level of 1400 kg.ha^{-1}, the exchangeable NH_4^+-N concentration was lower than at 2800 kg.ha^{-1} for all amendment sources. However, the percentages of exchangeable NH_4^+-N that came from fertilizer were quite similar. These percentages were 10, 13, 39, 57, and 52% for the same order of amendments as given for the higher fertilizer rate.

At 40 days, the concentration of exchangeable NH_4^+-N decreased, especially for SS and PM. The percentages of exchangeable NH_4^+-N that came from fertilizer were 10, 13, 30, 38, and 51% for SS, PM, FP, CM, and FO, respectively. The percentage of exchangeable NH_4^+-N coming from fertilizer was significantly affected at 40 days by fertilizer level (Table A-3); fertilizer applied at 2800 kg.ha^{-1} provide statistically higher N percentage from fertilizer than for the level at 1400 kg.ha^{-1} (data not shown).

Soil Reaction, Electrical Conductivity and Moisture

Analysis of variance for the effect of amendment and fertilizer level on soil pH, electrical conductivity (EC) and moisture content at four dates after application of treatments is presented in Table A-4. During the cropping season, the values for pH and EC were highest when SS and PM were used (Table 6). The pH values for these two treatments did not differ from each other at all four sampling dates. However, EC values were always highest from the SS and differed statistically from all other treatments at all four dates considered.

Table [illegible]. Main effect of amendment and fertilizer level on soil pH, EC and moisture content at four dates after application of treatments. Tomato experiment, 1982.

Treatments	pH	EC	Moisture	pH	EC	Moisture
		dS.m^{-1}	g.kg^{-1}		dS.m^{-1}	g.kg^{-1}
	7 days^			40 days		
Amendment+						
SS	6.11a^{y}	5.69a	200	5.98a	5.67a	156
PM	6.25a	2.42b	213	5.81a	3.58b	155
FP	5.53b	1.69c	213	5.45bc	3.15b	164
CM	5.40b	1.59cd	210	5.53bc	2.70c	148
FO	5.29b	1.11d	204	5.23c	3.14bc	149
F value	***	**	NS	***	***	NS
Fert. level (kg.ha^{-1})						
1400	5.70	2.00	209	5.58	3.44	155
2800	5.74	2.60	206	5.63	3.86	155
F value	NS	**	NS	NS	**	NS
	70 days^			110 days^		
Amendment+						
SS	5.60a	4.67a	121a	5.67a	4.30a	150a
PM	5.65a	3.56b	112a	5.79a	3.30b	146ab
FP	5.59a	3.58b	109a	5.65ab	3.14b	138ab
CM	5.41ab	3.02b	102ab	5.64ab	2.80b	132b
FO	5.21b	3.33b	89b	5.39b	2.95b	130b
F value	**	***	**	**	***	*
Fert. level (kg.ha^{-1})						
1400	5.40	3.70	106	5.54	3.27	140
2800	5.51	3.96	108	5.64	3.32	139
F value	NS	NS	NS	NS	NS	NS

NS, *, **, ***Not significant, significant at the 5%, 1% and 0.1% levels, respectively.

^{y}Amendment mean separation within columns by Duncan's Multiple Range Test.

^Days after application of treatments.

+See Table 3 for abbreviations.

Soil moisture content was highest when organic amendment sources were applied compared to that where inorganic fertilizer was used. This held throughout the crop season (Table 6). This effect was more relevant at 70 days after application of treatments (after a long period of low rainfall). At this time, all organic sources, except CM, differed statistically in moisture content than that for the FO treatments.

At 110 days, soil moisture content with SS was statistically higher than from CM and FO, but this was not statistically significant from PM and FP amendment sources.

Level of fertilizer did not significantly affect soil pH or moisture content at all four soil sampling dates (Table A-4). Electrical conductivity tended to be slightly higher with 2800 $kg.ha^{-1}$ of fertilizer and was significantly different from the level of 1400 $kg.ha^{-1}$ at 7 and 40 days after application of treatments (Table 6).

Soil reaction at 7 days showed a significant positive correlation with EC, NH_4^+-N in water, concentrations of Ca, K, and Cl. Significant correlations at 40 days were found between pH and EC, NO_3^--N, NH_4^+-N in water, Ca, Mg, K, Cl, and moisture content. However, no statistically significant correlation between pH and the above measurements was observed at 70 and 110 days (Table 7).

Soil EC was negatively correlated with moisture content only at 110 days. With all other above soil values, the correlation coefficient was positive (Table 7). Except with soil pH at 70 and 110 days, all combinations of correlation coefficients were significant. Soil NO_3^--N, NH_4^+-N, Ca, Mg, K, and Cl showed an average correlation coefficient (average of 4 dates) with EC of 0.59, 0.72, 0.51, 0.62, 0.70, and 0.68, respectively.

Table 7. Correlation coefficient between pH and EC and some soil properties at four dates after application of treatments. Tomato experiment, 1983.

	Days	pH	EC	NO_3^--N	NH_4^+-N	Ca	Mg	K	Cl	Moisture
		Correlation coefficients (r), %								
pH	7	-	59.1***	23.5	73.3***	66.9***	20.4	37.0*	49.9**	-20.0
	40	-	39.7*	40.8**	49.9***	32.7*	52.9***	37.8*	48.7**	-34.0*
	70	-	23.8	0.4	-5.3	-18.9	-18.5	16.1	-5.1	-0.5
	110	-	0.15	-14.7	-20.9	-0.8	-31.0	-11.0	-16.1	-14.0
EC	7	59.1***	-	59.2***	79.3***	68.9***	66.8***	51.0***	68.5***	-5.7
	40	39.7*	-	47.5**	83.3***	42.3**	75.2***	83.7**	80.3***	-2.7
	70	23.8	-	67.9***	66.8***	52.7***	51.1***	66.3***	63.6***	-15.9
	110	0.15	-	63.3***	60.4***	41.9**	58.4***	82.3**	63.6***	-38.9*

*, **, ***Significant correlation coefficient at the 5%, 1% and 0.1% levels, respectively.

Soil Organic Matter and Cation Exchange Capacity

Analysis of variances for pH measured in $CaCl_2$, organic matter (OM) and cation exchange capacity (CEC) are indicated in Table 8. At 7 days, only CEC was statistically different among amendment treatments.

Because CEC is greatly influenced by pH-dependent properties, the pH values in 0.5 M $CaCl_2$ were recorded. Soil pH values in $CaCl_2$ were slightly lower than corresponding pH values observed in water at 7 and 70 days after application of treatments (Tables 7 and 9). The soil pH values decreased in all amendment sources from 7 to 150 days. However, no statistically significant differences among treatments were observed at 7, 70, and 150 days (Table 8).

The organic amendments measureably increased soil OM content compared to that for FO treatment. The average OM value among the four organic amendments was 25, 25, and 32% higher than for values obtained for soil with FO at 7, 70, and 150 days, respectively (Table 8).

The highest OM values were obtained with SS amendment at all sampling dates. Organic matter values remained almost constant during the period sampled and this was observed for all amendment sources.

Cation exchange capacity decreased between the 7 to 150 day sample times in all treatments (Table 8). At 7 days, utilization of SS, PM, and FP gave the highest values but these were not statistically different from each other. However, these above amendments were statistically different from that for FO. The average CEC for soil with organic amendments (mean of four organic sources) was 48, 20, and 8% higher than the CEC found for soil with FO amendment at 7, 70, and 150 days, respectively (Table 8).

Table 8. Analysis of variance and treatment means for soil pH, OM, CEC at three dates after application of treatments. Tomato experiment, 1983.

Source of variation	df	Days after application of treatment								
		7	70	150	7	70	150	7	70	150
		Mean squares								
		pH (0.5 M $CaCl_2$)			OM			CEC		
Treatment	4	0.025	0.048	0.048	29.0	32.4	33.3	343.4*	105.9	86.6
Error	5	0.020	0.031	0.031	10.3	17.0	17.5	42.4	47.9	129.6
Amendment+		pH (0.5 M $CaCl_2$)			OM ($g.kg^{-1}$)			CEC mmol (1/2 Ca^{+2}).kg^{-1}		
SS		5.08	4.77	4.70	29.7	29.7	30.0	72.3a^y	52.3	52.0
PM		5.10	4.81	4.68	25.4	24.2	26.5	76.0a	54.3	43.3
FP		4.89	4.75	4.64	24.3	21.2	24.5	64.6ab	44.5	37.5
CM		4.73	4.64	4.60	20.9	21.7	22.1	53.2bc	39.5	36.0
FO		4.74	4.70	4.67	20.0	19.3	19.4	44.7c	39.6	38.7

*F value significant at the 5% level.

^{y}Treatment mean separation within columns by Duncan's Multiple Range Test, 5% level.

+See Table 3 for abbreviations.

Carbon Dioxide Evolution

The analysis of variance and the cumulative CO_2-C evolved with time for soil with both amendment sources and fertilizer levels, are shown in Table A-5 and Fig. 3. Trends in cumulative CO_2-C with time for amendment sources were similar. From 0 to 13 days of incubation, 80, 82, 77, 77 and 70% of the total cumulative CO_2-C were evolved from SS, PM, FP, CM and FO, respectively. Throughout the incubation period, PM had the highest values for cumulative CO_2-C. For all soil sampling dates, these values differed statistically from the other four amendments. The lowest values for CO_2-C evolution were obtained with FO and, except at the third date, these values were not statistically different from those obtained with CM treatment (Table A-5 and Fig. 3).

With increase in fertilizer level, the higher rate gave CO_2-C evolution always more cumulative than that at the lower rate.

Ion Concentration in Soil Water Extract

Statistical analysis of soil water extractable nutrients indicated that significant differences occurred among amendment sources for all nutrients (except for P at 7 days) and at all soil sampling dates (Table A-6). For fertilizer levels, only K at 7 days, Ca at 40 days and Ca, K, and P at 110 days showed statistically significant differences between the two fertilizer levels. The concentrations of Ca, Mg, K, P, and Cl during the cropping season are shown in Table 9. Highest Ca and K values were obtained with SS and PM amendments. These amendments did not differ statistically from each other, but they were statistically higher from the other three amendment sources, at all soil sampling dates.

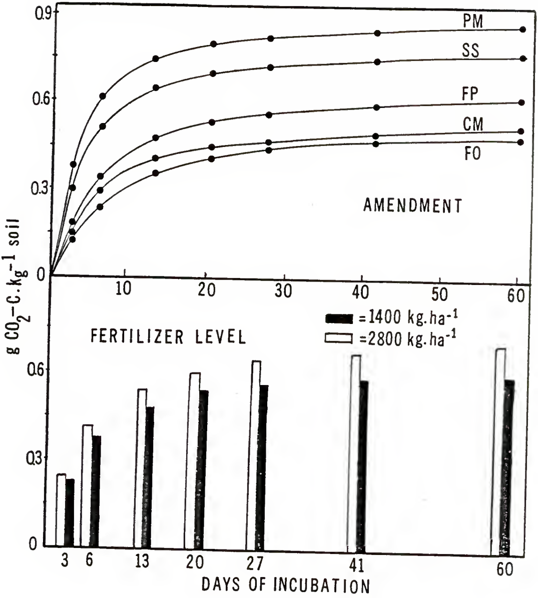

Fig. 3. Main effect of amendment and fertilizer level on cumulative carbon dioxide production. Tomato experiment, 1982. See Figure 2 for abbreviations.

Mg, K, P and Cl concentration in soil water extract at four dates after application of treatments. Tomato experiment, 1982.

Treatment	Ca	Mg	K	P	Cl	Ca	Mg	K	P	Cl
	------------	------------	------------	mg.kg^{-1}	dry soil	------------	------------	------------	------------	------------
			7 days^					40 days^		
Amendment^{+}										
SS	202a^{y}	72a	115a	0.53	375a	170a	76a	103a	0.68a	312a
PM	184a	25b	113a	0.49	291b	166a	25b	99a	0.54ab	187b
FP	112c	24b	94b	0.32	227c	128cb	22b	62b	0.40bc	114c
CM	142b	33b	85b	0.37	173c	87d	23b	56b	0.34c	119c
FO	109c	25b	84b	0.27	195c	118c	19b	55b	0.31c	152bc
F value	***	***	**	NS	***	***	***	***	***	***
Fert. level (kg.ha^{-1})										
1400	142	34	94	0.39	245	127	32	70	0.43	169
2800	157	37	102	0.40	253	140	33	80	0.48	184
F value	**	NS	NS	NS	***	NS	NS	**	NS	NS
			70 days^					110 days^		
Amendment^{+}										
SS	192a	68a	79a	0.54a	220a	162a	81a	67a	0.52a	205a
PM	187a	23b	80a	0.37ab	204a	154a	23b	65a	0.27b	141b
FP	102b	19b	60b	0.50a	152b	93b	15b	56b	0.23b	114b
CM	104b	20b	55b	0.34ab	153b	103b	17b	50b	0.19b	122b
FO	107b	21b	65b	0.14b	180ab	113b	19b	57b	0.14b	142b
F value	***	***	***	***	**	***	***	**	***	***
Fert. level (kg.ha^{-1})										
1400	129	30	67	0.35	174	110	30	54	0.21	142
2800	148	31	69	0.41	190	140	32	65	0.33	148
F value	NS	NS	NS	NS	NS	***	NS	***	**	NS

NS, *, **, ***Not significant, significant at the 5%, 1%, and 0.1% level, respectively.

^{y}Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

^After application of treatments.

$^{+}$See Table 3 for abbreviations.

Magnesium values were highest with SS, which were statistically different from the other treatments at all four dates considered. Phosphorus and Cl values also were highest with SS. Differences in P values among amendment sources were not consistent during the cropping season.

Under plastic mulching conditions, decrease in Cl values were 41, 51, 49, 29, and 27% from 7 to 110 days for SS, PM, FP, CM, and FO, respectively.

Tissue Analysis

Nitrogen Uptake by Leaf and Fruit

Amendment sources and fertilizer levels had statistically significant effects on tissue N as well as on percentage of N that came from fertilizer in tomato leaf and fruit (Table A-7).

For tomato leaf tissue, the concentration of N was highest when SS and PM amendments were used (Fig. 4). Significant difference in N uptake was observed between these two amendment sources compared to others at 63 and 93 days after transplant. The average leaf tissue N concentrations from tomato grown on SS and PM amended soil were 21, 35, and 39% higher than the average means among FP, CM, and FO at 41, 63, and 93 days after transplant, respectively. Lowest uptake of N occurred when FO was used and continued to be so at all three dates that leaf samples were taken.

The percentage of tissue N that came from fertilizer N showed an inverse trend to that observed for tissue N concentration (Fig. 4). Lowest values of N from fertilizer were observed for SS and PM treatments. At each leaf tissue sampling date, FO was significantly

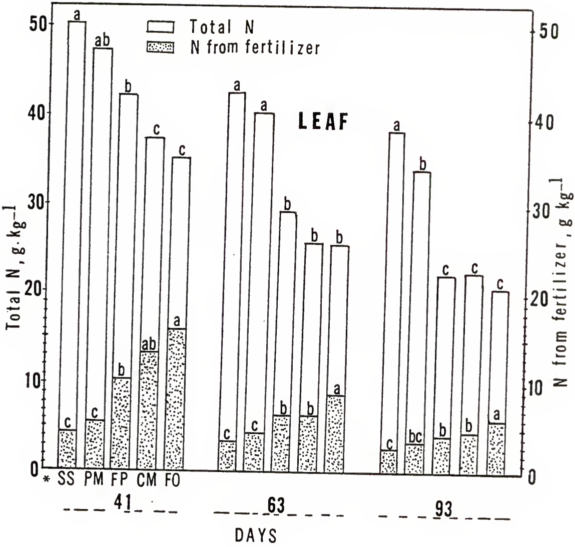

Fig. 4. Main effect of amendment sources on tomato leaf tissue N and N from fertilizer. Tomato experiment, 1982. (Mean separation between amendments by Duncan's Multiple Range Test, 5% level). *See Figure 2 for abbreviations. The sequence of amendments at 63 and 93 days is the same as that at 41 days.

different from SS and PM amendments in regard to the percentage of N from fertilizer (Fig. 4).

Total N concentration in tomato fruit was lower than observed for tomato leaf tissue (Fig. 5). However, N concentration in the tomato fruit was almost the same among amendments during the cropping season. Highest N concentration occurred with SS followed by that for PM. As observed for tomato leaf, the lowest N concentration in the fruit was found with FO and this was statistically different from SS and PM during the cropping season.

The percentage of total N coming from fertilizer in fruit showed similar trends to those observed in tomato leaf at all sampling dates. Increases in total N concentration was associated with decrease in the percentage of N coming from fertilizer.

At the first two tomato fruit sampling dates, N from fertilizer for FP, CM, and FO treatments did not differ statistically from each other. However, at all three fruit samplings, fruit from SS and PM had significantly less N from fertilizer than found for FP, CM, or FO treatments and there was no difference between SS and PM (Fig. 5).

Main effects of fertilizer levels on tissue N concentration and N derived from fertilizer for tomato leaf and fruit are shown in Table 10. An increase in the amount of fertilizer applied resulted in a higher N concentration in fruit tissue and a higher amount of N coming from fertilizer N.

Significant difference between the two fertilizer levels for tissue N was observed at 41, 63, and 93 days for leaf and 63 and 85 days for fruit (Table A-7).

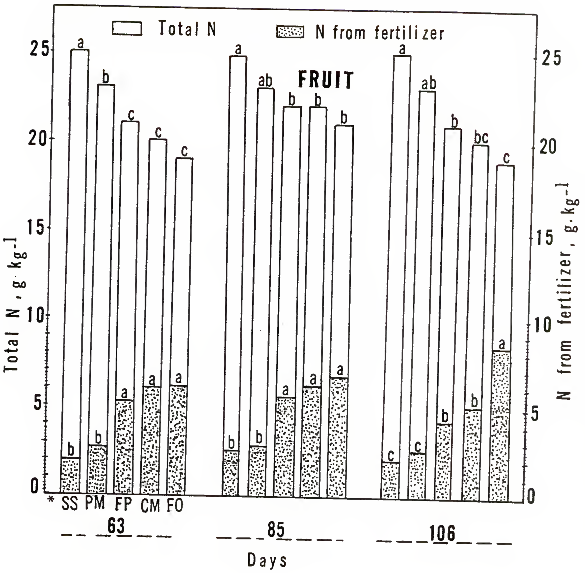

Fig. 5. Main effect of amendment sources on tomato fruit N and N from fertilizer. Tomato, 1982. (Mean separation between amendments by Duncan's Multiple Range Test, 5% level).
*See Figure 2 for abbreviations. The sequence of amendments at 85 and 106 days is the same as that at 63 days.

Table 10. Main effect of fertilizer levels on tissue N concentration and N from fertilizer for tomato leaf and fruit at three dates after transplant. Tomato experiment, 1982.

Fertilizer level kg.ha^{-1}	Leaf			Fruit		
	Days after transplant					
	41	63	93	63	85	106
	Total N, g.kg^{-1}					
1400	40.8	30.6	26.0	21.6	22.1	21.3
2800	43.8	34.5	29.1	22.4	23.8	22.3
F value	*	***	***	*	**	NS
	N from fertilizer, g.kg^{-1}					
1400	8.5	4.0	2.8	3.8	3.9	2.8
2800	11.5	7.1	4.7	5.0	5.9	4.7
F value	***	***	***	**	**	**

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

Fertilizer at 2800 $kg.ha^{-1}$ increased leaf N and percentage of total N coming from fertilizer in leaf when compared to those at the lower fertilizer level. These fertilizer rate effects at 41 days resulted in a 7% increase in leaf tissue N and a 35% increase in N derived from fertilizer. At 63 days, the increase in leaf N due to the higher fertilizer level was 13% and the increase in N derived from the fertilizer was 43%. At 93 days, leaf N and percentage of the leaf N that came from the higher fertilizer level increased 10 and 40%, respectively.

In fruit, the N concentration and percentage of total N coming from fertilizer increased both with an increase in fertilizer level from 2800 $kg.ha^{-1}$ to 1400 $kg.ha^{-1}$. These effects of fertilizer at the higher rate were 3 and 24% at 63 days, 7 and 34% at 85 days and 4 and 40% at 106 days for fruit N and percentage of N derived from fertilizer, respectively.

Nutrient Concentration in Leaf and Fruit

Amendment source and fertilizer level effects on leaf tissue macronutrients at three dates after transplant are shown in Table 11. Leaf samples taken throughout the season changed in mean concentrations of Ca, Mg, K, and P, but did not show significant differences for main effect of fertilizer levels or interaction between amendment sources and fertilizer levels. The main effect of amendment sources on nutrient concentration on leaf tissue was statistically significant for Mg at 41 days and 93 days; for K at 41, 63, and 93 days; and for P at 93 days after transplant (Table 11). Calcium concentration was not influenced by amendment source and, in general, showed little fluctuation during the season for all amendment sources.

Table 11. Analysis of variance and main effect of amendment sources and fertilizer levels on macronutrient concentration of tomato leaf at three dates after transplant. Tomato experiment, 1982.

Source of variation	df	Days after transplant											
		41	63	93	41	63	93	41	63	93	41	63	93
		Mean square											
		Ca			Mg			K			P		
Block	3	52.0*	41.5	9.4	0.2	0.1	2.9	49.1**	110.6*	41.6	1.1	1.6*	2.4***
Amendment (A)	4	45.2	32.2	3.8	4.3***	4.3	22.5***	46.0**	149.0**	325.6***	0.3	0.4	1.2***
Fert. level (F)	1	0.0	19.0	0.0	0.2	4.4	0.0	8.8	8.6	63.7	0.0	0.4	0.2
AxF	4	8.0	35.2	37.3	0.1	2.0	0.7	32.9	20.6	32.7	1.2	0.3	0.3
Error	27	19.1	16.3	19.4	0.5	1.9	1.0	14.1	32.4	16.4	0.6	0.4	0.3
Amendment+		$g.kg^{-1}$											
SS		16.5	16.5	15.1	5.7a^y	4.7	8.6a	31.2a	29.2a	27.9a	4.4	3.4	3.6a
PM		17.0	16.1	15.2	4.5b	4.1	5.5b	27.9ab	24.7ab	19.0b	4.7	3.6	3.1ab
FP		14.6	16.4	14.5	4.1b	3.7	5.1b	27.2ab	18.4b	11.9bc	4.3	3.3	2.7b
CM		15.8	14.8	14.3	4.0b	3.4	4.7b	25.5b	19.7b	16.0bc	4.2	3.2	2.8b
FO		11.7	13.9	14.1	4.0b	3.6	4.4b	25.2b	17.2b	13.3c	4.1	3.1	2.7b
F value		NS	NS	NS	***	NS	***	**	**	***	NS	NS	***
Fert. level ($kg.ha^{-1}$)													
1400		15.2	15.2	14.5	4.4	3.6	5.6	26.9	21.4	16.4	4.3	3.2	3.0
2800		15.3	16.5	14.7	4.5	3.8	5.7	27.9	22.3	18.9	4.4	3.4	3.1
F value		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.
^{y}Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.
+See Table 3 for abbreviations.

Both K and P concentrations decreased from 41 to 93 days after transplant. The Mg concentration decreased from 41 to 63 days and then increased from 63 to 93 days. Application of SS and PM amendments resulted in highest tissue content of Ca, Mg, K, and P at all three sampling dates. Lowest concentration of these nutrients in the leaf always was observed when FO was used.

Amendment source and fertilizer level effects on macronutrients concentration of tomato fruit at three dates after transplant are shown in Table 12. Interaction effect between amendment and fertilizer levels was not statistically significant during the cropping season. Nutrient concentration in immature fruit sampled at 63 days after transplant (22 days before the first harvest) indicated a significant difference only for main effect of amendment source on Ca concentration. Highest Ca concentration was found with SS and PM, whereas lowest Ca concentration was found when FO was used.

Mature fruit sampled at 85 days after transplant (first harvest) indicated significant differences for both main effect of amendment and fertilizer level on Ca, Mg, and K concentrations. Calcium concentration was highest with PM and differed statistically from Ca content for the other four amendment sources. This significant difference was not observed for later fruit samples. Magnesium and K concentrations were highest with SS and PM and both showed significant differences from FO treatment. Concentration of Ca, Mg, and K of tomato fruit at 85 days were significantly higher for the higher fertilizer rate.

For mature fruit, sampled at 106 days after transplant (near the end of fruiting period), the analysis of variance indicated significant difference for main effect of amendment source on Mg, K, and P

Table 12. Analysis of variance and main effect of amendment sources and fertilizer levels on macronutrient concentration of tomato fruit at three dates after transplant. Tomato experiment, 1982.

Source of variation	df	Days after transplant											
		63	85	106	63	85	106	63	85	106	63	85	106
		Mean square											
		Ca			Mg			K			P		
Block	3	0.48	1.88**	0.31	0.03	0.16*	0.08**	33.9	141.8	32.1	0.28	1.28	0.12
Amendment (A)	4	1.61**	2.00***	0.21	0.08	0.13*	0.16***	98.6	347.9*	503.0***	1.10	0.79	0.44*
Fert. level (F)	1	0.27	2.02*	0.00	0.02	0.27**	0.00	66.0	403.2*	46.6	0.01	1.02	0.00
AxF	4	0.22	0.28	0.14	0.02	0.06	0.00	61.8	44.2	7.6	0.43	0.31	0.15
Error	27	0.50	0.29	0.18	0.04	0.04	0.02	70.8	98.3	12.6	0.44	0.50	0.14
Amendment+		$g.kg^{-1}$											
SS		3.6ab[y]	3.2b	2.2	1.7	1.7a	1.6a	30.0	39.2a	40.5a	5.4	5.5	2.0a
PM		3.9a	4.0a	2.4	1.6	1.7a	1.4b	29.0	35.0ab	31.2b	5.7	5.6	2.0a
FP		3.3abc	3.1b	2.0	1.6	1.5b	1.3b	27.2	32.3abc	24.3c	5.6	5.5	1.7ab
CM		3.0bc	3.1b	2.0	1.5	1.5b	1.3b	26.6	25.2bc	23.8c	5.2	5.4	1.6b
FO		2.8c	2.6b	2.0	1.4	1.4b	1.3b	21.0	23.7c	20.6c	4.8	4.8	1.5b
F value		**	***	NS	NS	**	***	NS	**	***	NS	NS	*
Fert. level ($kg.ha^{-1}$)													
1400		3.26	3.0	2.1	1.5	1.4	1.4	25.5	27.9	27.0	5.3	5.1	1.8
2800		3.43	3.4	2.2	1.6	1.7	1.4	25.0	34.3	29.1	5.4	5.5	1.8
F value		NS	**	NS	NS	**	NS	NS	*	NS	NS	NS	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

[+] See Table 3 for abbreviations.

concentrations. Magnesium and K concentration were highest with SS and both were statistically different from the other four amendment sources. Also, P concentration was highest with SS but was only statistically significant over those for CM and FO amendments.

Analysis of variance for the effect of amendment source and fertilizer level on Cd, Mn, Zn, Fe, Al and Cu concentration on tomato leaf and fruit at three dates after transplant is shown in Table A-8. The concentration of these elements in tomato leaf and fruit tissue at all three sampling dates differed with amendment sources but were not influenced by fertilizer level.

At the early cropping season or 41 days after transplant (except for Al), the main effect of amendment sources for all nutrients determined in leaf indicated a significant difference between SS and all other amendment sources (Table 13). Increase in fertilizer level also gave a significant increase in uptake of Zn and Cu.

In mid-season, at 63 days after transplanting, uptake of Cd, Al, and Cu were significantly different among amendment sources (Table 13). Concentration of these elements in tomato leaf was highest with SS and was statistically different from those with FO. No statistically significant effect was observed between fertilizer levels on the concentrations of Cd, Mn, Zn, Al, and Cu in tomato leaf.

Later in the crop season, at 93 days after transplant, concentration of the above elements showed significant differences among amendment sources (Table 13). With SS, concentration of all nutrients was highest and was significantly different from all other four amendment sources. Fertilizer level effect was statistically different only

Table 13. Main effect of amendment source and fertilizer levels on Cd, Mn, Zn, Fe, Al and Cu concentration of tomato leaf at three dates after transplant. Tomato experiment, 1982.

Treatment	Cd	Mn	Zn	Fe	Al	Cu
	$mg.kg^{-1}$					
Amendment[+]	41 days after transplant					
SS	0.59a[y]	203a	43a	109a	142	9.0a
PM	0.36b	147b	26b	86b	86	6.8b
FP	0.38b	107c	26b	90b	103	5.9bc
CM	0.34b	108c	26b	82b	91	5.3cd
FO	0.31b	81c	24b	84b	87	4.6d
F value	***	***	***	***	NS	***
Fertilizer level ($kg.ha^{-1}$)						
1400	0.44	127	25	90	88	5.9
2800	0.44	132	33	91	115	6.8
F value	NS	NS	***	NS	NS	**
Amendment[+]	63 days after transplant					
SS	0.54a	261	39	91	189a	6.8a
PM	0.31b	262	33	82	150abc	5.2ab
FP	0.30b	302	26	66	160ab	3.2bc
CM	0.35b	277	39	61	107bc	4.4bc
FO	0.31b	249	27	72	135bc	2.8c
F value	*	NS	NS	NS	*	***
Fertilizer level ($kg.ha^{-1}$)						
1400	0.34	286	31	73	146	4.6
2800	0.34	295	37	76	150	4.4
F value	NS	NS	NS	NS	NS	NS
Amendment[+]	93 days after transplant					
SS	0.91a	84a	56a	123a	121a	8.3a
PM	0.51b	55b	42b	85b	88b	4.3b
FP	0.48b	77ab	48ab	76bc	100b	2.9c
CM	0.47b	74ab	46b	75c	100b	3.3bc
FO	0.38b	51b	47ab	68c	83b	2.8c
F value	***	*	*	***	*	***
Fertilizer level ($kg.ha^{-1}$)						
1400	0.47	70	48	86	100	4.0
2800	0.61	68	47	85	95	4.7
F value	**	NS	NS	NS	NS	**

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

[+] See Table 3 for abbreviations.

for Cd and Cu concentration. Higher concentration of both Cd and Cu in the leaf was found at the higher fertilizer level.

Immature fruit samples (63 days after transplant) indicated significant differences existed among amendment sources for Mn, Zn and Cu concentrations (Table A-8). Highest concentration of these three elements occurred with SS and lowest for FO (Table 14). Main effect of fertilizer level was not significant for these elements.

At 85 days after transplant (first fruit harvest), significant differences among amendment sources were found for Mn, Al, and Cu concentrations. At this time, Mn and Cu concentration, at the fertilizer level at 2800 $kg.ha^{-1}$, was statistically significant from the 1400 $kg.ha^{-1}$ fertilizer level.

At the last fruit sampling, except for Al and Cd, all other listed elements were affected significantly by amendment sources (Table 14). Highest Mn, Zn, Fe, and Cu concentration were observed with SS, differing statistically from the other four amendment sources. Increased fertilizer levels did not affect significantly these elements concentrations in tomato fruit.

Cucumber Experiment. Fall, 1982

Cucumber Fruit Yield

Residual effects of organic amendment and fertilizer levels from the prior tomato experiment, Spring 1982, were evaluated by seeding cucumber in the Fall of the same year on original plots for tomato.

Analysis of variance indicated statistical significance for main effect of amendment on both early and final average fruit weight and on fruit yield (Table 15). Main effect of fertilizer level and interaction

Table 14. Main effect of amendment source and fertilizer level on Cd, Mn, Zn, Fe, Al and Cu concentration of tomato fruit at three dates after transplant. Tomato experiment, 1982.

Treatment	Cd	Mn	Zn	Fe	Al	Cu
	µg.kg^{-1}	----------------	--------	mg.kg^{-1}	--------	----------------
Amendment[+]				63 days after transplant		
SS	2.0	22a[y]	43a	109a	142	9.0a
PM	1.9	12b	26b	86b	86	6.8b
FP	2.0	14b	26b	90b	103	5.9bc
CM	2.1	14b	26b	82b	91	5.3cd
FO	1.7	15b	24b	84b	87	4.6d
F value	NS	**	**	NS	NS	***
Fertilizer level (kg.ha^{-1})						
1400	1.9	14	23	41	45	5.2
2800	2.0	17	25	43	42	5.4
F value	NS	NS	NS	NS	NS	NS
Amendment[+]				85 days after transplant		
SS	1.8	26a	27	27	28b	6.8a
PM	1.9	15b	28	22	40a	5.7ab
FP	1.8	16b	25	23	24b	4.8bc
CM	1.6	15b	23	23	23b	4.8bc
FO	1.7	18b	21	20	21b	3.8c
F value	NS	***	NS	NS	*	***
Fertilizer level (kg.ha^{-1})						
1400	1.7	15	23	22	29	4.8
2800	1.8	21	26	24	26	5.5
F value	NS	***	NS	NS	NS	*
Amendment[+]				106 days after transplant		
SS	1.3	28a	26a	45a	25	7.2a
PM	1.1	14c	22b	28b	23	5.3b
FP	1.1	14c	18c	21b	23	3.4c
CM	1.0	14c	18c	26b	20	4.0c
FO	1.0	20b	18c	27b	22	4.2bc
F value	NS	***	***	**	NS	***
Fertilizer level (kg.ha^{-1})						
1400	1.1	17	20	31	21	4.8
2800	1.1	19	20	28	24	4.8
F value	NS	NS	NS	NS	NS	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

[+] See Table 3 for abbreviations.

Table 15. Analysis of variance and main effect of amendments and fertilizer level for average fruit weight and fruit yield. Cucumber, experiment, 1982.

Source of variation	df	Average fruit weight		Fruit yield	
		Early	Final	Early	Final
		---- Mean squares ----			
Blocks	3	331.4	2298.3	28.90*	170.6***
Amendment (A)	4	19618.2***	17093.8***	762.49***	1932.4***
Fertilizer level (F)	1	3298.2	1292.0	14.95	37.9
AxF	4	113.6	272.2	8.06	15.8
Error	27	2242.0	1204.5	6.29	16.6
Amendment[+]		---- g ----		---- $mg.kg^{-1}$ ----	
SS		393.6a[y]	325.4a	27.3a	43.1a
PM		341.9b	296.1b	22.4b	37.8b
FP		316.4b	262.6b	9.0c	16.0c
CM		340.5b	276.0b	9.8c	15.7c
FO		241.4c	206.4c	4.4d	7.9d
F value		***	***	***	***
Fertilizer level ($kg.ha^{-1}$)					
1400		323.3	274.8	14.0	23.2
2800		337.6	286.2	15.2	25.1
F value		NS	NS	NS	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

[+] See Table 3 for abbreviations.

between amendment sources and fertilizer levels was not statistically significant.

Average early season fruit weight (first two harvests) was highest with SS and lowest with FO. Highest average fruit weight and fruit yield were obtained for residual effects of SS. The PM, FP, and CM residual effects were not different and were more than for FO residual effect.

The final average fruit weight was lower than that observed in the early season for all amendment sources. However, significant differences that existed among amendments were the same as observed earlier in the season.

Early and final fruit yield ranged from 4.4 to 27.3 $Mg.ha^{-1}$ and 7.9 to 43.1 $Mg.ha^{-1}$, respectively. Higher early and final fruit yields were observed with SS and were greater than those from PM. Compared to FO, these two amendments (SS and PM) increased yield to 22.9 and 17.9 $Mg.ha^{-1}$ and 35.2 and 29.9 $Mg.ha^{-1}$ for early and final yield, respectively.

Significant correlation (Pearson product-moment) observed between early yield and early average fruit weight was $r=0.66$ ($P<0.001$), and between final yield and early average fruit weight was $r=0.73$ ($P<0.001$). Between final yield and final average fruit weight, the relationship was $r=0.75$ ($P<0.001$).

Soil Analysis

Nitrogen Availability

For soil N extracted at 10 days after cucumber seeding significant differences between amendment sources were observed (Table 16). Main effect for fertilizer level and the interaction between amendment sources and fertilizer levels were not statistically significant.

Table 16. Analysis of variance and mean effect of amendment and fertilizer level on soil N extracted, pH, EC and moisture at 10 days after cucumber seeding. Cucumber experiment, 1982.

Source of Variation	df	Water extract NO_3^--N	Water extract NH_4^+-N	KCl extract NH_4^+-N	Available total N	pH	EC	Moisture
		Mean square						
Block	3	27.5*	0.3	0.11	24.9	0.06	0.38	1312.1
Amendment (A)	4	490.5***	74.6***	53.31***	1440.0***	0.32***	0.85**	10032.2
Fert. level (F)	1	4.0	0.4	0.00	3.1	0.00	0.27	6900.3
AxF	4	6.8	0.5	0.09	6.9	0.05	0.40	9901.1
Error	22	8.0	1.0	0.26	9.9	0.04	0.14	10505.3
Amendment[+]		$mg.kg^{-1}$					$dS.m^{-1}$	$g.kg^{-1}$
SS		20.3a	7.2a	7.0a	34.7a	5.70a	2.03a	258
PM		20.2a	6.5a	6.5a	33.2a	5.86a	1.33b	173
FP		8.2b	1.8b	2.4b	11.8b	5.64ab	1.17b	186
CM		6.6bc	1.2b	2.2b	10.7b	5.47b	1.39b	184
FO		4.0c	1.0b	1.5c	6.6c	5.40b	1.40b	173
F value		***	***	***	***	**	**	NS
Fert. level ($kg.ha^{-1}$)								
1400		12.2	3.5	3.9	19.7	5.97	2.39	182
2800		11.6	3.6	3.9	19.1	5.98	2.56	209
F value		NS	NS	NS	NS	NS	NS	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[+]See Table 3 for abbreviations.

Highest NO_3^--N, NH_4^+-N in water, exchangeable NH_4^+-N and available total N concentrations were found when SS and PM had been used. These two treatments were not statistically different, but were, however, significantly different from the other three amendment sources. Utilization of FO had the lowest concentration of all forms of N extracted. Nitrate-N concentrations observed for all amendment sources were higher than for NH_4^+-N in water and exchangeable NH_4^+-N concentrations. With SS, PM, FP, CM and FO, the percentages of total available N due to NO_3^--N were 58, 61, 69, 61 and 60%, respectively, at 10 days after cucumber seeding.

Soil Reaction, Electrical Conductivity and Moisture

Analysis of variance for the residual effect of amendment and fertilizer level on soil pH, EC and moisture is shown in Table 16.

Main effect of amendment source was statistically significant for pH and EC. Fertilizer level and interaction effects were not statistically significant. Soil reaction ranged from 5.86 to 5.40 and EC from 2.03 to 1.40 $dS.m^{-1}$. Highest pH and EC values were observed with SS and PM.

No significant differences were found for soil moisture between amendments (Table 16).

Ion Concentration in Water Extract

Statistical analysis for ion concentration in soil water extract at 10 days after cucumber seeding indicated some significant differences existed among amendment sources (Table 17). Interaction effect between amendment and fertilizer levels was not statistically significant. Main effect of amendment source was observed for Ca, K and P. Soluble K concentration varied from 82 to 63 $mg.kg^{-1}$, Ca concentration from 50 to 32

Table 17. Analysis of variance and main effect of amendment and fertilizer levels on Ca, Mg, K, P and Cl concentration in soil water extract 10 days after cucumber seeding. Cucumber experiment, 1982.

Source of variation	df	Ca	Mg	K	P	Cl
		----------	----------	Mean square	----------	----------
Blocks	3	40.2	114.0	433.9	0.007	4851.7
Amendment (A)	4	552.5**	48.1	498.4*	0.032*	5859.3
Fertilizer levels (F)	1	17.2	18.2	854.7*	0.000	5191.5
AxF	4	144.2	19.3	131.6	0.001	3746.5
Error	27	52.1	33.2	166.7	0.019	4599.6
Amendment[+]		----------	----------	$mg.kg^{-1}$ dry soil	----------	----------
SS		50a[y]	17	82a	0.43a	151
PM		36b	14	78ab	0.36ab	90
FP		36b	11	74ab	0.26b	95
CM		34b	12	65bc	0.30b	89
FO		32b	12	63c	0.26b	91
F value		*	NS	*	*	NS
Fertilizer level ($kg.ha^{-1}$)						
1400		36	12	68	0.33	92
2800		38	14	77	0.34	115
F value		*	NS	*	NS	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

[+] See Table 3 for abbreviations.

$mg.kg^{-1}$ and P concentration from 0.43 to 0.26 $mg.kg^{-1}$. For soluble Ca, K and P, SS amendment had the highest concentrations whereas the lowest concentration were observed when CM or FO were used. This was similar in pattern to that for NO_3^--N and NH_4^+-N in water shown in Table 15. However, NO_3^--N and NH_4^+-N concentrations were much lower than soluble K concentration. Since soluble Cl was higher than NO_3^--N concentration, the possibility remained that some fertilizer salts remained after tomato plant removal. The treatments did not differ in Cl content at this sampling time.

Tissue Analysis

Nitrogen in Leaf and Fruit

Total N concentration and percentage of this total that came from fertilizer differed significantly with amendments. Fertilizer levels and interaction between amendment source and fertilizer levels were not statistically significant in leaf or fruit samples (Table A-9).

The highest total N concentration in leaf and fruit was observed with SS and PM amendments. These two amendments were statistically different from the other three amendments (Fig. 6). Percentage of the total N in leaf and fruit samples that came from the fertilizer N were very low for all amendment sources. These data observed among amendment sources showed that very little of the N applied for tomato remained for cucumber either in leaf or fruit.

Nitrogen concentration in fruit for all amendment sources were lower than N concentration observed in leaf. However, significant differences observed among treatments were similar (Fig. 6).

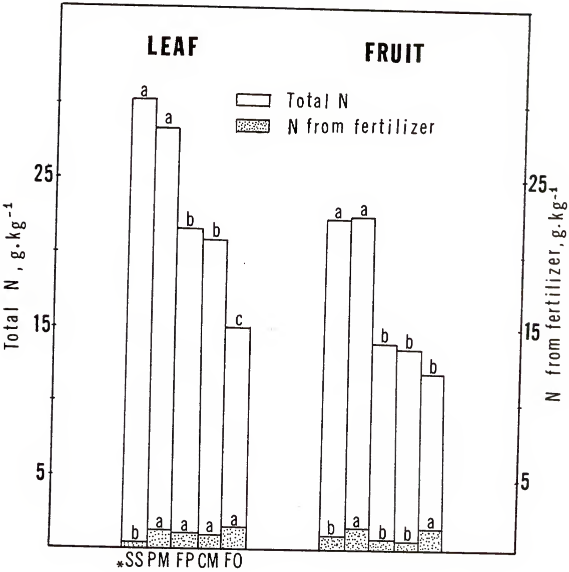

Fig. 6. Main effect of residual amendment sources on total N and N from fertilizer on cucumber leaf and fruit at 40 and 64 days after seeding, respectively. (Mean separation by Duncan's Multiple Range Test, 5% level).
*See Figure 2 for abbreviations. The sequence of amendments for fruit is the same as that for leaf.

Nutrient Concentration in Leaf and Fruit

Calcium and K in leaf and K concentration in fruit were affected significantly by amendment sources (Table 18). Fertilizer levels had significant effect only in K concentration in fruit. Interaction between these two factors was not significant for leaf or fruit Ca, Mg, K and P concentrations.

Calcium and K concentrations of cucumber leaf were not significantly different when SS, PM and FP were utilized. For Ca concentrations, these three amendments were statistically different from CM and FO. However, for K concentration only SS was statistically higher than CM and FO (Table 18). Potassium concentration in fruit was highest with SS, differing statistically from the other four amendment sources. At fertilizer level of 2800 $kg.ha^{-1}$, the K concentration in fruit was slightly higher than observed at 1400 $kg.ha^{-1}$.

Amendment source significantly affected Cd and Al concentration of leaf and Mn by fruit (Table 19). Fertilizer level significantly affected the concentration of leaf Zn and of fruit Mn and Zn. Interactions between amendment source and fertilizer level were not statistically significant. Highest Cd and Al concentration in leaf and Mn in fruit were obtained when SS amendment was used. Cadmium concentrations of fruit were below the detection limit of 0.02 $mg.kg^{-1}$. Aluminum concentration of leaf, when SS and PM were used, was not statistically different, but both these amendments showed significantly more Al than from the other three amendment sources. Fertilizer level of 2800 $kg.ha^{-1}$ slightly increased Zn concentration of leaves and of fruit Mn and Zn concentrations.

Table 18. Analysis of variance and main effect of amendment source and fertilizer level on Ca, Mg, K and P concentration on cucumber leaf and fruit. Cucumber experiment, 1982.

Source of variation	df	Leaf				Fruit			
		Ca	Mg	K	P	Ca	Mg	K	P
		Mean square							
Block	3	23.2	8.5	59.1	1.4	0.50	0.05	54.7	2.6
Amendment (A)	4	201.2***	9.4	264.7*	2.7	0.17	0.06	203.9***	0.5
Fert. level (F)	1	42.1	2.0	3.5	0.0	0.01	0.12	120.0*	0.0
AxF	4	22.8	4.3	13.3	1.3	0.78	0.06	58.6	0.2
Error	27	25.8	4.5	96.7	1.0	0.38	0.07	26.1	0.4
Amendment[+]		$g.kg^{-1}$							
SS		27.0a[y]	8.8	39.2a	5.1	2.8	2.9	44.0a	5.8
PM		27.6a	8.6	32.5ab	5.2	2.8	2.7	34.1b	5.6
FP		25.4a	9.5	29.8ab	5.5	2.7	2.7	31.7b	5.1
CM		18.4b	6.8	27.5b	5.3	2.7	2.8	34.2b	5.7
FO		15.4b	7.4	24.0b	4.1	2.5	2.9	32.0b	5.4
F value		***	NS	*	NS	NS	NS	***	NS
Fert. level ($kg.ha^{-1}$)									
1400		22.4	8.0	30.3	4.9	2.7	2.9	33.5	5.6
2800		20.3	8.4	30.9	4.9	2.7	2.8	37.0	5.7
F value		NS	NS	NS	NS	NS	NS	*	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test.

[+] See Table 3 for abbreviations.

Table 19. Analysis of variance and main effect of amendment source and fertilizer level on Cd, Mn, Zn, Fe and Al concentrations in leaf and Mn, Zn, Fe and Al in cucumber fruit. Cucumber experiment, 1982.

Source of variation	df	Leaf					Fruit$^{\wedge}$			
		Cd	Mn	Zn	Fe	Al	Mn	Zn	Fe	Al
		Mean square								
		40 days after seeding					64 days after seeding			
Block	3	0.005	9760	533*	218	7469	9.5	36.4*	127.4*	293.1
Amendment (A)	4	0.021*	4415	139	528	29111***	174.4***	16.3	30.7	177.5
Fert. level (F)	1	0.001	1985	1093**	6	4462	115.8**	66.3*	2.8	14.9
AxF	4	0.011	7298	131	488	9722	29.9	7.1	7.3	48.2
Error	27	0.006	4302	149	217	4074	9.8	12.0	34.8	71.7
Amendment^{+}										
SS		0.32a^{y}	320	54	70	281a	20.8	29.6	31.7	32.1
PM		0.23b	290	54	85	212c	16.3	29.2	31.6	41.0
FP		0.20b	288	58	81	280a	11.3	28.9	34.6	43.6
CM		0.20b	288	55	77	233bc	11.2	29.8	32.1	39.6
FO		0.20b	254	46	65	160c	9.5	32.4	35.9	34.6
F value		*	NS	NS	NS	***	***	NS	NS	NS
Fert. level (kg.ha^{-1})										
1400		0.24	281	48	75	230	12.1	28.7	32.9	37.6
2800		0.24	295	58	76	236	15.5	31.3	33.4	38.8
F value		NS	NS	*	NS	NS	**	*	NS	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

^{y}Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

$^{\wedge}$Cd values were below detection limit.

$^{+}$See Table 3 for abbreviations.

Tomato Experiment. Spring, 1983

Tomato Fruit Yield

Periodical visual observations of tomato growth during the season showed that FO and BC treatments were not as vigorous as those with SS and PM.

Analysis of variance for the effect of amendment sources and rates in combination with fertilizer levels (21 treatments) on tomato fruit yield is shown in Table A-10. Statistically significant differences were observed among treatments for total fruit yield and yields in size categories 2, 3 and 4. Using a contrast procedure, 20 orthogonal contrasts were studied and several significant differences were obtained (Table A-10).

Fruit yield in size category 1 had no statistically significant differences among treatments. However, when either SS at the higher rate was used with 2800 $kg.ha^{-1}$ of fertilizer or when PM was used at 11.2 $Mg.ha^{-1}$ with 1400 $kg.ha^{-1}$ of fertilizer, the highest yields were obtained, which were 46.5 and 58.7 $Mg.ha^{-1}$, respectively (Table A-10 and Table 20).

Yield of fruit in size 2 from the combinations of PM rates and fertilizer levels had statistically different effects. Both PM rates had quadratic response to increasing levels of fertilizer applied (Table A-10 and Table 20). In this same fruit size category, main effect of BC rates was statistcally significant. With BC at 1.12 $Mg.ha^{-1}$ the average yield was 27.4 $Mg.ha^{-1}$ and with BC at 2.24 $Mg.ha^{-1}$ the average yield was 34.5 $Mg.ha^{-1}$. Organic amendments had an average fruit yield of 38.5 $Mg.ha^{-1}$ which was significantly different from the average yield of 28.6 $Mg.ha^{-1}$ with inorganic amendments. However, between organic sources (SS

Table 20. Means of tomato fruit yield when amendment sources, amendment rates and fertilizer levels were utilized. Tomato experiment, 1983.

Amendment		Fert. level	Fruit yield, size category+				Total yield
Source‡	Rate		1	2	3	4	
	Mg.ha^{-1}	kg.ha^{-1}	Mg.ha^{-1}				
			Inorganic amendment				
FO		1400	40.7	30.6	9.8	2.6	83.7
		2800	29.4	30.0	10.6	3.0	73.0
		4200	33.4	36.5	18.1	5.6	93.6
BC	1.12	1400	34.1	24.4	13.1	3.3	74.9
	1.12	2800	33.0	27.3	11.4	2.9	74.6
	1.12	4200	33.5	30.6	13.2	4.5	81.6
BC	2.24	1400	37.0	33.8	14.0	3.2	88.0
	2.24	2800	32.4	33.8	13.8	4.3	84.3
	2.24	4200	43.4	36.1	15.1	3.5	98.1
			Organic amendment				
SS	11.2	0	33.2	33.0	15.0	3.6	84.8
	11.2	1400	37.7	32.7	10.8	2.7	83.9
	11.2	2800	43.6	36.2	11.8	2.9	94.6
SS	22.4	0	37.3	36.0	16.2	4.2	93.9
	22.4	1400	36.9	33.0	10.9	2.5	83.3
	22.4	2800	46.5	46.9	20.0	5.0	118.4
PM	11.2	0	45.4	39.4	14.0	3.4	102.2
	11.2	1400	58.7	49.7	19.0	3.9	131.3
	11.2	2800	31.1	28.0	12.0	3.0	74.1
PM	22.4	0	40.4	43.6	19.4	4.2	107.6
	22.4	1400	34.9	37.6	19.8	6.1	98.4
	22.4	2800	38.3	45.7	26.2	7.3	117.5

+Mean fruit weights were as follows: 1) 250 g, 2) 250 g, 3) 115 g and 4) 85 g.

‡FO is fertilizer only; SS is sewage sludge from Orlando, Florida; PM is poultry manure from a commercial enterprise; BC is bentonite clay from Aberdeen, Mississippi (calcium bentonite).

vs PM) and inorganic sources (FO vs BC), no significant difference was observed (Table A-10).

Yield of size 3 tomatoes had a significant linear response to fertilizer rates when SS was used in combination with fertiizer. The main response to fertilizer rates was significantly quadratic. Fruit yields also were different between PM rates. The average fruit yields at the PM rate of 11.2 and 22.4 $Mg.ha^{-1}$ were 15 and 21.8 $Mg.ha^{-1}$, respectively (Table 20). At both PM rates, fruit yields increased quadratically with increase in fertilizer levels. Average fruit yield produced when organic amendments were used, was 16.2 $Mg.ha^{-1}$. This fruit yield was significantly different from 13.2 $Mg.ha^{-1}$ produced by inorganic amendments. No statistical difference was observed between average fruit yield produced with FO and BC treatments. However, average fruit yield observed with PM (18.4 $Mg.ha^{-1}$) was significantly different from that observed with SS (14.1 $Mg.ha^{-1}$).

In fruit size category 4, yields were much less than those found for larger size fruit. Increase in level of applied fertilizer to FO treatments resulted in significant linear yield response. As observed in fruit size category 3, the main effect of fertilizer when combined with SS had a significantly quadratic response. Poultry manure at 22.4 $Mg.ha^{-1}$ gave a higher fruit yield than for PM at 11.2 $Mg.ha^{-1}$. Also, the average fruit yield for PM was significantly higher than the average fruit yield for SS. Interaction between PM rates and fertilizer levels was statistically significant (Table A-10).

The significance between blocks noted for fruit in size category 1 was also found for the total yield but not for fruit in the 2, 3 or 4 size categories (Table A-10). Total fruit yields ranged from 73 to 131

$\mathrm{Mg.ha^{-1}}$ (Table 20). Highest yield was obtained with PM at 11.2 $\mathrm{Mg.ha^{-1}}$ when combined with 1400 $\mathrm{kg.ha^{-1}}$ of fertilizer. Lowest total fruit yield was obtained with F0 at 2800 $\mathrm{kg.ha^{-1}}$.

Increase in fertilizer levels in combination with SS and BC did not follow a significant linear or quadratic trend for total fruit yield. However, when PM amendment was combined with fertilizer levels, there was a quadratic yield response. When PM was applied at 11.2 $\mathrm{Mg.ha^{-1}}$, total fruit yield increased when 1400 $\mathrm{kg.ha^{-1}}$ was applied and then decreased when 2800 $\mathrm{kg.ha^{-1}}$ of fertilizer was utilized. At 22.4 $\mathrm{Mg.ha^{-1}}$ of PM, the response to fertilizer rates was higher at the higher fertilizer rate than that observed at the lower one (Table 20). Average total fruit yield obtained with organic amendments (99.1 $\mathrm{Mg.ha^{-1}}$) was statistically different from that obtained with inorganic amendments (82.6 $\mathrm{Mg.ha^{-1}}$).

Comparison of amendments which received fertilizer at 1400 and 2800 $\mathrm{kg.ha^{-1}}$ was made in a separate analysis of variance in Table A-11. Significant interaction was found between amendment sources and fertilizer level for fruit in sizes 2, 3 and total fruit yields. These responses are presented in Table 21.

At 1400 $\mathrm{kg.ha^{-1}}$ of fertilizer, yields in fruit size category 2 was not statistically significant for PM at either 11.2 and 22.4 $\mathrm{Mg.ha^{-1}}$. However, the highest yield was found for PM and this was statistically different from the other five treatments. At fruit size category 3,

Table 21. Interaction mean between amendment source and fertilizer level on tomato fruit yield in size categories 2, 3 and total yield. Tomato experiment, 1983.

Amendment[+]	Fertilizer level (kg.ha^{-1})	
	1400	2800
	Mg.ha^{-1}	
	Fruit yield, size 2	
SS (11.2 Mg.ha^{-1})	32.7 b[y] A[z]	36.1 ab A
SS (22.4 Mg.ha^{-1})	33.3 b B	46.8 a A
PM (11.2 Mg.ha^{-1})	49.7 a A	25.9 b B
PM (22.4 Mg.ha^{-1})	37.6 ab A	45.7 a A
BC (1.12 Mg.ha^{-1})	24.4 b A	27.3 b A
BC (2.24 Mg.ha^{-1})	33.8 b A	33.8 b A
FO	30.6 b A	30.4 b A
	Fruit yield, size 3	
SS (11.2 Mg.ha^{-1})	10.8 b A	11.8 c A
SS (22.4 Mg.ha^{-1})	10.9 b B	20.0 a A
PM (11.2 Mg.ha^{-1})	18.9 a A	12.0 c B
PM (22.4 Mg.ha^{-1})	19.7 a A	26.2 a A
BC (1.12 Mg.ha^{-1})	13.1 b A	11.4 c A
BC (2.24 Mg.ha^{-1})	14.0 b A	13.7 b A
FO	9.8 b A	10.6 c A
	Total fruit yield	
SS (11.2 Mg.ha^{-1})	84.0 b A	94.0 ab A
SS (22.4 Mg.ha^{-1})	83.7 b B	118.4 a A
PM (11.2 Mg.ha^{-1})	131.3 a A	74.1 b B
PM (22.4 Mg.ha^{-1})	98.4 b A	117.5 a A
BC (1.12 Mg.ha^{-1})	74.9 b A	74.7 b A
BC (2.24 Mg.ha^{-1})	88.0 b A	84.3 ab A
FO	83.9 b A	73.2 b A

[y] Amendment means within columns followed by same small letter are not significantly different by Duncan's Multiple Range Test, 5% level.

[z] Amendment means within rows followed by same capital letter are not significantly different by F test at 5% level.

[+] See Table 20 for abbreviations.

both PM rates gave similar yields which were significantly different from those of the other five amendments.

When fertilizer was applied at 2800 kg.ha^{-1}, yields in fruit size category 2 were highest from SS at both rates and from PM at 22.4 Mg.ha^{-1} but were not significantly different from each other. When SS and PM were used at the higher rate in combination with 2800 kg.ha^{-1} of fertilizer, fruit yields of 46.8 and 47.7 Mg.ha^{-1} were obtained, respectively. Both fruit yields were significantly higher than yields for the other four treatments (Table 21). At fruit size 3, yields were highest from either SS or PM at 22.4 Mg.ha^{-1}. However, both above yields were significantly different from those of the other five treatments (Table 21).

Total fruit yield at the lower fertilizer level was 131.3 Mg.ha^{-1} when used in combination with PM at 11.2 Mg.ha^{-1} (Table 21). This fruit yield was statistically more than from the other treatments.

With 2800 kg.ha^{-1} of fertilizer, no significant difference in total fruit yield was found between SS at both rates or PM at 22.4 Mg.ha^{-1} or BC at 2.24 Mg.ha^{-1}. However, with amendment with SS and PM at the higher rate, yields were significantly different from the other three treatments, namely, PM at 11.2 Mg.ha^{-1}, BC at 1.12 Mg.ha^{-1} and FO treatments.

Fruit yield comparisons for the same treatment at two fertilizer levels are also shown in Table 21. Significant differences were observed to be the same for fruit size categories 2 or 3 as those for total fruit yield. Only when SS was applied at 22.4 Mg.ha^{-1} or PM at 11.2 Mg.ha^{-1} did yields differ at the two fertilizer levels. However, when SS was used, the highest fruit yields at size 2, 3 and total were obtained when fertilizer was applied at 2800 kg.ha^{-1}. When PM was used, the highest fruit yield was observed when fertilizer was applied at 1400 kg.ha^{-1}.

Soil Analysis

Nitrogen Availability

Statistical analysis among 21 treatments for each soil N form determined during the tomato cropping season is shown in Table A-12. These 21 treatment responses were examined throughout 20 orthogonal contrasts shown in Table A-13. In general, soil that received SS or PM amendments had higher water extractable NO_3^--N and NH_4^+-N, exchangeable NH_4^+-N and available total N concentrations than soil that received BC or FO amendments (Tables 22 and 23).

Organic amendments used at the higher rate generated higher soil NO_3^--N concentration than that observed at the lower rate (Table 22). Except at 19 days after application of treatments, soil NO_3^--N at the higher rate of both SS and PM was significantly different from those at the lower rate (Table A-13). Linear positive main effect of fertilizer rate was statistically significant at all four dates after application of the amendments. However at 80 days, interaction effects between PM amendment rates and fertilizer levels were observed. Similar interaction effect for SS amendment was noted at 19 and 80 days. When such an interaction effect was not significant, main effect of fertilizer was linear.

Nitrate-N concentration trends observed with BC and FO had a linear and positive significant trend for main effect of fertilizer from 1400 to 4200 kg.ha^{-1} (Table A-13). This was observed at 19, 40, 80 and

Table 22. Effects of organic amendment sources and rates and of fertilizer levels for soil N extracted at four dates after application of treatments. Tomato experiment, 1983.

	Sewage sludge						Poultry manure					
	$11.2\ Mg.ha^{-1}$			$22.4\ Mg.ha^{-1}$			$11.2\ Mg.ha^{-1}$			$22.4\ Mg.ha^{-1}$		
	Fertilizer level ($kg.ha^{-1}$)											
Time	0	1400	2800	0	1400	2800	0	1400	2800	0	1400	2800
Days	Water extracted NO_3^--N, $mg.kg^{-1}$											
19	9	18	39	13	16	18	16	20	37	18	21	31
48	116	146	180	176	220	194	158	170	175	189	245	247
80	43	62	107	146	155	163	90	92	105	132	190	193
111	25	53	69	80	85	102	26	47	90	90	117	121
	Water extracted NH_4^+-N, $mg.kg^{-1}$											
19	54	87	94	65	91	97	32	35	57	86	109	120
48	33	43	57	43	46	70	20	24	52	15	64	67
80	13	26	30	20	25	28	16	22	23	14	32	40
111	3	10	16	6	7	8	2	2	6	5	5	4
	1 M KCl extracted NH_4^+-N, $mg.kg^{-1}$											
19	95	134	141	151	159	228	96	116	141	219	228	258
48	53	88	105	74	78	163	44	74	90	77	95	100
80	11	27	44	55	57	118	20	26	32	17	34	47
111	6	15	33	13	15	19	4	8	12	4	9	14
	Mehlich I extracted NH_4^+-N, $mg.kg^{-1}$											
19	77	130	137	175	227	258	87	111	143	228	295	319
48	37	84	102	81	94	111	36	51	101	34	121	125
80	9	47	34	32	37	103	19	21	30	15	31	75
111	6	14	25	13	14	19	3	3	5	2	5	8
	Total available N (water NO_3^--N + 1 M KCl NH_4^+-N) $mg.kg^{-1}$											
19	104	152	180	164	175	246	112	136	178	237	249	289
48	169	234	285	250	298	357	202	244	265	266	340	347
80	54	89	151	201	212	281	110	118	137	149	224	240
111	31	68	102	93	100	121	30	50	102	94	126	135

Table 23. Effects of inorganic amendment sources and rates and of fertilizer levels on soil N extracted at four dates after application of treatments. Tomato experiment, 1983.

	Fertilizer only			Bentonite clay					
				1.12 Mg.ha^{-1}			2.24 Mg.ha^{-1}		
	Fertilizer level								
Time	1400	2800	4200	1400	2800	4200	1400	2800	4200
Days	Water extracted NO$_3^-$-N, mg.kg^{-1}								
19	45	66	110	53	61	87	57	77	89
48	52	75	89	86	140	166	120	193	200
80	25	39	68	22	35	40	32	40	59
111	11	24	44	11	24	46	19	30	41
	Water extracted NH$_4^+$-N, mg.kg^{-1}								
19	25	29	60	20	38	53	22	41	51
48	17	21	34	20	34	36	9	20	28
80	5	6	9	4	8	11	5	7	9
111	2	3	4	2	2	3	2	2	2
	1 M KCl extracted NH$_4^+$-N, mg.kg^{-1}								
19	54	55	108	48	70	85	64	72	98
48	35	45	54	35	48	58	43	43	65
80	7	8	10	6	9	17	6	7	14
111	3	5	5	3	4	7	4	2	4
	Mehlich I extracted NH$_4^+$-N, mg.kg^{-1}								
19	45	46	123	41	67	70	59	74	86
48	24	48	65	36	57	60	36	52	66
80	8	9	10	7	11	14	6	7	15
111	2	5	5	2	4	5	3	4	3
	Total available N (water NO$_3^-$-N + 1 M KCl NH$_4^+$-N, mg.kg^{-1}								
19	99	121	218	101	131	172	121	149	187
48	87	120	143	121	188	224	163	236	265
80	32	47	78	28	44	57	38	47	73
111	14	29	49	14	28	53	23	32	45

111 days after application of treatments. Significant difference between the two BC rates was observed at 19 and 48 days and the higher NO_3^--N concentration was found when BC was at 2.24 $Mg.ha^{-1}$. Interaction between BC rates and fertilizer levels was not significant. As observed with organic amendments, the highest NO_3^--N concentration was produced at 48 days after application of both BC and FO treatments (Tables 22 and 23).

For all soil sampling comparisons between organic amendments, the average of NO_3^--N for PM was statistically higher than the average observed for SS. Also, at all samplings, the averages of NO_3^--N for organic amendments was statistically higher than that observed for inorganic amendments (Tables A-13, 22 and 23).

Water extractable ammonium-N decreased throughout the season for all treatments (Table 22 and 23). When organic amendments were used these NH_4^+-N concentrations had a different pattern of statistical significance than that given with inorganic amendments (Table A-13). Ammonium-N levels were alike from SS at both rates and did not differ between rate during the cropping season. With both rates of PM, NH_4^+-N was statistically different from each other at all soil sampling dates. The higher NH_4^+-N concentration was observed at higher PM rate.

At 111 days after application of treatments, the interaction between fertilizer level and SS rate was statistically significant for water extractable NH_4^+-N concentration. However, at 19, 48 and 80 days, the main effect of fertilizer level within SS rate was significantly linear (Table A-13).

With PM at the last three samplings, of interaction between PM rates and fertilizer level was significant. However, at 80 and 111 days, increase in NH_4^+-N in water extracts due to fertilizer level was linear and positive with both PM rates. At 48 days, the trend observed was quadratic for fertilizer level at both PM rates.

At both BC rates in combination with fertilizer levels, the main effect for fertilizer level was significantly linear at 19, 40 and 80 days for NH_4^+-N concentration in water (Table A-13). However, for FO amendment, only at 19 days there was a linear effect that was statistically significant.

Average means of water extractable NH_4^+-N found when PM was utilized were significantly higher than average means found for SS at 19, 48 and 111 days. Also, it was observed at all soil samplings that average means of NH_4^+-N were significantly higher for organic amendments than those observed with inorganic amendments (Tables A-13, 22 and 23).

Ammonium-N concentration obtained either by 1 M KCl and by Mehlich I extract showed quite similar values between extractants at all soil sampling dates and with all treatments (Tables 21 and 22). Consequently, only trends in 1 M KCl values for NH_4^+-N are reported. Especially after 19 and 48 days, the exchangeable NH_4^+-N concentration was higher than corresponding water extractable NH_4^+-N concentration for all treatments (Tables 21 and 22). This indicated the degree of NH_4^+-N held on the exchange sites.

Exchangeable NH_4^+-N differences between amendment rates were noted for both PM and SS amendments at the first soil sampling. At 22.4 $Mg.ha^{-1}$ of organic amendments, higher exchangeable NH_4^+-N concentrations were found than at the lower amendment level for the same fertilizer level (Tables A-13 and 22).

Significant interaction between SS rate and fertilizer level was observed at all soil sampling dates for exchangeable NH_4^+-N. At the first three sampling dates, at both rates of SS, there was a linear response to levels of fertilizer. At 111 days, quadratic trends were observed for fertilizer levels with both SS rates (Table A-13). Significant interaction for exchangeable NH_4^+-N between PM rate and fertilizer level was observed at both 80 and 111 days after application of treatments. At both dates, the exchangeable NH_4^+-N concentration increased linearly with increase in fertilizer levels at both PM rates (Tables A-13 and 22).

With inorganic amendments, significant trends were observed for exchangeable NH_4^+-N concentrations and these were similar to those reported above for corresponding NH_4^+-N concentration in water extract (Table 23).

Analysis of variance and significant regression equations for available total N (combination of NO_3^--N in water plus NH_4^+-N in 1 $\underline{M}$ KCl) found during the cropping season are shown in Tables A-12 and 24.

When organic amendments were used, significant differences in available total N (TN) were found between rate of both SS and PM at all four soil sampling dates (Table A-13). At 19 days for SS and 80 days for PM, TN values showed a significant quadratic trend to increase of fertilizer level. However, at all other dates for both of these amendments, a linear positive response to fertilizer level was found for these TN values (Tables A-13 and 24).

Significant interaction of TN between amendment rate and fertilier level at 19 and 111 days for SS was observed. At the first sampling, significant quadratic responses of TN were obtained at both rates of

Table 24. Regression equations for amendment sources as a function of each fertilizer level for total available N (TN) during the cropping season. Tomato experiment, 1983.

Amendment rate	Days	Regression equations	r^2
$Mg.ha^{-1}$		Fertilizer only	
	19	$TN^{+} = 151.9 - 0.063x + 1.9x10^{-5}x^2$	96.7***
	48	$TN = 27.8 + 0.042x$	85.6***
	80	$TN = 6.56 + 0.00019x$	88.7***
	111	$TN = -2.6 + 0.012x$	76.3**
		Sewage sludge	
11.2	19	$TN = 104.1 + 0.042x - 5.4x10^{-5}x^2$	62.8*
22.4	19	$TN = 165.1 - 0.014x + 1.5x10^{-6}x^2$	88.9**
11.2	48	$TN = 172.9 + 0.041x$	82.8***
22.4	48	$TN = 248.9 + 0.038x$	79.6**
11.2	80	$TN = 50.9 + 0.032X$	94.3***
22.4	80	$TN = 191.7 + 0.028x$	62.5*
11.2	111	$TN = 21.0 + 0.030x$	96.0***
22.4	111	$TN = 84.4 + 0.012x$	71.7**
		Poultry manure	
11.2	19	$TN = 110.4 + 0.023x$	73.0**
22.4	19	$TN = 233.3 + 0.018x$	50.8*
11.2	48	$TN = 206.4 + 0.022x$	74.2**
22.4	48	$TN = 277.4 + 0.029x$	41.2*
11.2	80	$TN = 111.4 + 0.008 + 3.02x10^{-6}x^2$	90.9**
22.4	80	$TN = 149.2 + 0.074x - 1.4x10^{-5}x^2$	80.9**
11.2	111	$TN = 26.1 + 0.025x$	93.3***
22.4	111	$TN = 98.0 + 0.014x$	52.2**
		Bentonite clay	
1.12	19	$TN = 64.8 + 0.025x$	90.4***
2.24	19	$TN = 87.3 + 0.023x$	81.1***
1.12	48	$TN = 74.2 + 0.037x$	69.0**
2.24	48	$TN = 119.0 + 0.036x$	71.6**
1.12	80	$TN = 15.3 + 0.010x$	92.1***
2.24	80	$TN = 18.3 + 0.012x$	58.6*
1.12	111	TN = NS	NS
2.24	111	$TN = 10.2 + 0.008x$	81.6**

[+] Available total N.

NS, *, **, ***Not significant, significant at the 5%, 1% and 0.1% levels, respectively.

fertilizer. However, at the last sampling, for both SS rates significantly linear positive trends were observed. A similar interaction was significant at 80 days for PM, at which time both rates had a significantly quadratic response for available N (Tables A-13 and 24).

When inorganic amendments were utilized, TN at the first two sampling dates was significantly different between BC rates (Table A-13). No interaction for TN was obtained between BC rate and fertilizer level during the season. At 19 days for FO amendment, available TN values were significantly quadratic in response to fertilizer level. Otherwise, the increases observed for available TN gave a linear response to increase in fertilizer level throughout the season (Table A-13).

Average means for available TN among organic amendments were significantly higher than those observed for inorganic amendments at all soil samplings (Tables A-13, 22 and 23).

Highest available TN concentrations were maintained in the soil during the tomato growing season from treatments receiving SS and PM, each at the high rate (Figs. 7 and 8).

Sewage sludge, PM, and BC at all three fertilizer levels resulted in the same response for available TN during the cropping season. Soil values indicated that available TN increased from 19 to 48 days and then decreased thereafter (Figs. 7 and 8). Note that the decreases observed after 48 days for all amendments were greater at both rates. Slope of these response curves was quite similar between BC rates.

When FO was used, there was always a decrease in available total N from 19 to 111 days at all three fertilizer levels (Fig. 8).

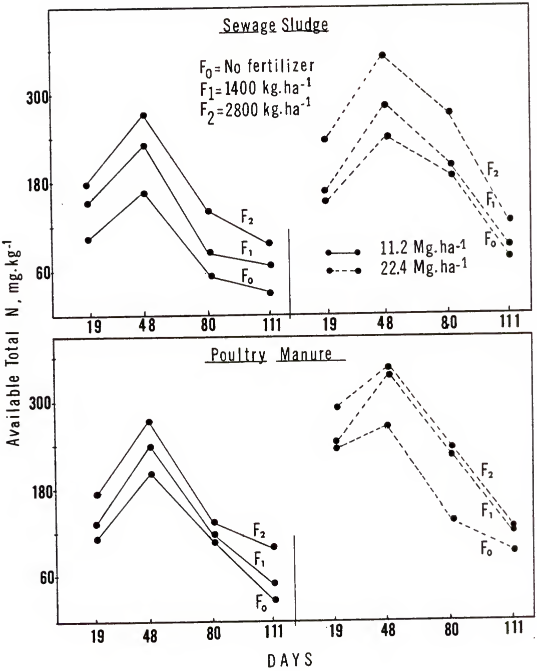

Fig. 7 Sewage sludge and poultry manure treatment means for available total N in the soil at four dates after application of treatments. Tomato experiment, 1983.

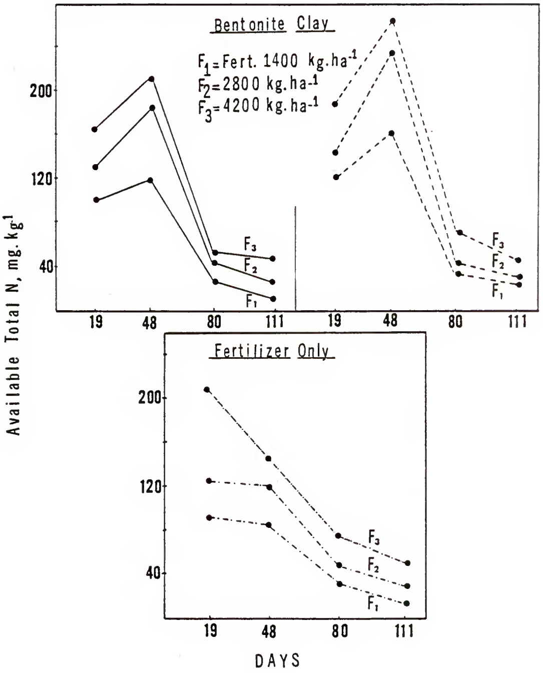

Fig. 8 Bentonite clay and fertilizer only treatment means for available total N in the soil at four dates after application of treatments. Tomato experiment, 1983.

At each soil sampling, increase in fertilizer level also increased the total available TN in the soil. This effect persisted for both organic and inorganic amendments and for amendment rates.

When comparing amendment sources at fertilizer levels of 1400 and 2800 $kg.ha^{-1}$, seven treatments are considered as stated previously. Analysis of variance and main effect of these treatments and fertilizer levels on NO_3^--N and available TN in soil are shown in Table 25.

At 19 days after application of treatments, soil that received inorganic amendments had the highest NO_3^--N concentration. For BC applied at 2.24 $Mg.ha^{-1}$, much more NO_3^--N was generated than at 1.14 $Mg.ha^{-1}$. For FO treatments, NO_3^--N was statistically different from that for both SS or PM treatments (Table 25). At the three subsequent soil sampling dates, soil with organic amendments had the highest NO_3^--N concentrations. Poultry manure at 22.4 $Mg.ha^{-1}$, followed by SS at the same rate, had the highest NO_3^--N concentrations. These two treatments were statistically different and also differed significantly from the other five treatments at these dates. Poultry manure and SS at the lower rate gave statistically significant different levels of NO_3^--N than at the higher rate at 48 and 80 days after application of treatments. However, inorganic amendments did not differ significantly in soil NO_3^--N production for soil sampled at 48, 80, and 111 days (Table 25). This indicated that organic amendments were continuing NO_3^--N production during the season.

At all soil samplings, fertilizer at 2800 $kg.ha^{-1}$ generated higher NO_3^--N concentration than at the lower rate (Table 25). Statistical analysis for available TN indicated that main effect of amendment and main effect of fertilizer were significant at all four soil sampling

Table 25. Analysis of variance and main effect of treatments and fertilizer level on NO_3^--N and total available N in soil during the cropping season. Tomato experiment, 1983.

Source of variation	df	NO_3^--N	Avail. total N	NO_3^--N	Avail. total N	NO_3^--N	Avail. total N	NO_3^--N	Avail. total N
		19 days		48 days		80 days		111 days	
		Mean square							
Block	2	24	610	1106	2785	86	303	7	2
Treatments (T)	6	2268***	19178***	21363***	46460***	25218***	48065***	9456***	12021***
Fert. level (F)	1	2142***	14459***	5786***	20904***	2107***	8602***	3017***	4832***
TxF	6	84	415	1004	938	221	845**	224	301*
Error	26	54	483	576	842	167	207	130	140
		$mg.ha^{-1}$							
Amendment⁺									
SS (11.2 $Mg.ha^{-1}$)		28c[y]	166c	80d	260b	80d	117[z]	61c	98[z]
SS (22.4 $Mg.ha^{-1}$)		17d	211b	159b	328a	159b	247	93b	118
PM (11.2 $Mg.ha^{-1}$)		28c	158cd	98c	254b	98c	127	68c	82
PM (22.4 $Mg.ha^{-1}$)		26c	269a	191a	344a	191a	232	119a	135
BC (1.12 $Mg.ha^{-1}$)		57b	116e	29e	154d	29e	37	18d	23
BC (2.24 $Mg.ha^{-1}$)		67a	136de	36e	199c	36e	42	24d	29
FO		55b	110e	32e	104e	32e	39	18d	24
F value		***	***	***	***	***	***	***	***
Fert. level $kg.ha^{-1}$									
1400		33	148	82	212	82	106	49	61
2800		47	185	97	257	87	134	66	84
F value		***	***	***	***	***	***	***	***

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

[y] Treatment means separation within columns by Duncan's Multiple Range Test, 5% level.

[z] Interaction significant.

⁺See Table 20 for abbreviations.

dates. However, interaction between these two factors was significant at 80 and 111 days (Table 25). Available TN at the first two samplings was highest for PM and SS at 22.4 $Mg.ha^{-1}$ and, at these two amendment sources, were significantly higher than those from the other five treatments. Lowest available total N was observed in soil samples that received F0 treatments.

Interaction means between amendment sources and fertilizer levels are shown in Table 26. At both fertilizer levels at 80 and 111 days, no differences were observed for available TN among inorganic amendments and the latter were statistically lower than those of the organic amendments.

At 80 days, SS and PM at the higher amendment rate resulted in higher available TN than at the lower rate, which held for both fertilizer levels.

At 111 days, differences between both fertilizer levels for available TN were less than at 80 days. Also, at this sampling, both SS and PM at the higher rate continued to have more available TN than at the lower amendment rate. The exception was that soil with SS at the lower rate with the higher fertilizer level also had the highest level of available N. These data showed clearly that organic amendments maintained more available N than did inorganic amendments and continued to maintain a residual effect from the fertilizer.

Soil Reaction, Electrical Conductivity and Moisture

Analysis of variance for soil pH, EC and moisture indicated that significant differences existed between treatments for pH and EC (not shown). Significant contrasts, mean square for soil pH and EC during the cropping season are shown in Table A-14.

Table 26. Interaction means between amendment source and fertilizer level for total available N at two dates after application of treatments. Tomato experiment, 1983.

Amendment[+]	Fertilizer levels (kg.ha^{-1})			
	1400	2800	1400	2800
	Available TN, mg.kg^{-1}			
	80 days[^]		111 days[^]	
SS (11.2 Mg.ha^{-1})	115 b[y]	182 c	78 c	119 ab
SS (22.4 Mg.ha^{-1})	237 a	309 a	106 b	129 a
PM (11.2 Mg.ha^{-1})	140 b	161 c	57 c	107 b
PM (22.4 Mg.ha^{-1})	256 a	280 b	131 a	139 a
BC (1.12 Mg.ha^{-1})	32 c	54 d	16 d	31 c
BC (2.24 Mg.ha^{-1})	43 c	54 d	24 d	34 c
FO	37 c	53 d	17 d	32 c

[^] Days after application of treatments.

[y] Means separation within columns by Duncan's Multiple Range Test, 5% level.

[+] See Table 20 for abbreviations.

Means for soil pH, EC and moisture for organic amendment sources and rates are shown in combination with three levels of fertilizer in Table 27.

Soil pH values were slightly decreased for both organic amendments at each sampling time when fertilizer was increased from 0 to 2800 $kg.ha^{-1}$. However, a substantial decrease in soil pH was observed at each fertilizer level when fertilizer was combined with organic amendments, as shown from 19 to 80 days after application of treatments (Table 26). In general, soil pH values at 22.4 $Mg.ha^{-1}$ of either organic amendment tended to be slightly higher than at 11.2 $Mg.ha^{-1}$. However, only at 19 days for SS, did pH value at the higher rate differ from that at the lower rate (Tables A-14 and 26). At 80 and 111 days, the main effect of fertilizer on soil pH values was a significant linear negative trend when SS was used (Tables A-14 and 27). At corresponding fertilizer levels and amendment rate, soil pH from samples with PM were higher than that with SS amendment. The average pH values obtained for PM at 19, 48, 80 and 111 days were significantly higher than those obtained for SS at all dates above (Tables A-14 and 27). All pH values were in an optimum range for tomato.

Soil EC increased with fertilizer level. At both amendment sources and rates and for all soil sampling dates, this increase in EC was noted. From 19 to 111 days, the EC values decreased with all treatments. This was indicative of salt removal by tomato plants or lost by leaching. Significant difference in EC was observed between amendment rates for SS and PM at 48 and 80 days. For both amendments, the higher rate had higher EC values (Tables A-14 and 28). At all four samplings for both organic amendments, a significant linear positive

Table 27. Effects of organic amendment source and rates and of fertilizer levels on soil pH, EC and soil moisture at four dates after application of treatments. Tomato experiment, 1983.

	Sewage sludge						Poultry manure					
	11.2 $Mg.ha^{-1}$			22.4 $Mg.ha^{-1}$			11.2 $Mg.ha^{-1}$			22.4 $Mg.ha^{-1}$		
	Fertilizer level ($kg.ha^{-1}$)											
Time	0	1400	2800	0	1400	2800	0	1400	2800	0	1400	2800
Days	pH											
19	6.88	6.93	6.50	7.19	6.99	7.07	7.26	6.82	7.10	7.41	7.37	6.97
48	6.22	6.01	5.87	6.23	5.99	6.10	6.33	6.15	6.39	6.47	6.37	6.34
80	6.06	5.91	5.60	6.19	6.08	5.73	6.27	6.16	6.13	6.37	6.13	6.30
111	6.36	6.31	5.91	6.33	6.27	6.17	6.57	6.41	6.44	6.66	6.50	6.34
	EC, $dS.m^{-1}$											
19	1.52	2.74	3.86	1.68	2.67	3.81	1.86	2.65	3.50	1.84	3.07	3.52
49	1.12	1.78	3.09	1.47	2.11	3.25	1.41	1.98	3.13	1.75	2.68	3.28
80	0.63	1.16	1.64	1.06	0.99	2.08	0.89	1.16	1.57	0.93	1.66	1.76
111	0.73	1.17	1.84	0.60	1.19	1.86	0.70	1.17	1.79	0.78	1.23	1.86
	Soil moisture, $g.kg^{-1}$											
19	178	185	170	181	180	171	183	188	191	173	186	179
48	160	170	160	183	168	161	169	170	173	171	172	165
80	111	116	120	99	117	114	112	106	125	106	153	138
111	126	123	128	134	141	127	113	129	123	134	127	130

Table 28. Effects of inorganic amendments sources, rates and fertilizer levels on soil pH, EC and soil moisture at four dates after application of treatments. Tomato experiment, 1983.

	Fertilizer only			Bentonite clay					
				1.12 $Mg.ha^{-1}$			2.24 $Mg.ha^{-1}$		
	Fertilizer level								
Time	1400	2800	4200	1400	2800	4200	1400	2800	4200
Days	pH								
19	6.71	6.37	6.27	6.22	6.37	6.34	6.11	6.66	6.49
49	6.49	6.19	6.18	6.16	6.23	6.04	6.33	6.45	6.42
80	6.15	6.12	5.86	6.50	6.07	5.88	6.24	6.42	6.26
111	6.55	6.57	6.41	6.65	6.31	6.12	6.56	6.59	6.43
	EC, $dS.m^{-1}$								
19	1.71	2.68	3.67	2.27	2.87	3.35	2.28	2.85	3.33
48	1.00	1.57	2.68	1.20	1.86	2.86	1.04	1.86	2.90
80	0.85	0.92	1.54	0.72	1.00	1.47	0.75	1.31	1.42
111	0.64	0.88	1.71	0.68	1.44	1.65	0.67	1.14	1.75
	Soil moisture, $g.ha^{-1}$								
19	193	178	199	180	186	184	192	204	197
48	184	163	178	167	182	174	178	189	176
80	117	98	133	128	120	99	147	133	119
111	158	142	137	137	149	144	154	145	142

main effect of fertilizer level was observed. An interaction between SS and PM rates and fertiizer level was significant only at 80 days. Average EC means for PM and SS was statistically different only at 48 days (Table A-14).

Means for soil pH, EC and moisture for inorganic amendment sources are shown in Table 28. As observed with organic amendments, pH and EC values decreased from 19 to 80 days after application of treatments. At 80 and 111 days, the main effect of fertilizer with BC amendment was a significant linear decrease in pH values when the fertilizer level was increased.

Electrical conductivity values when FO was used were observed to be a significantly linear and positive response to fertilizer level at 19 and 48 days and a quadratic response at 80 and 111 days. However, when BC was applied, the response observed to fertilizer level was, at all soil samplings, significantly linear and positive (Tables A-14 and 28). Average EC values for FO and BC were significantly different at 48 and 111 days.

Average pH and EC means obtained with organic amendments was compared with those observed with inorganic amendments (Table A-14). For soil pH, only at 19 days did significantly higher pH value for organic amendments become evident. However, for EC at the last three soil samplings, soil with organic amendment had significantly higher values for EC than observed for inorganic amendments. This indicated mineralization of these amendments.

In order to compare all four amendment sources, two rates of SS, PM, BC and FO at 1400 and 2800 kg.ha^{-1} of fertilizer were selected.

Analysis of variance and main effect of these treatments on soil pH, EC and soil moisture are shown in Tables A-15 and 29.

Main effect of amendment was significant at 19, 80, and 111 days for soil pH and at all soil samplings for EC. Main effect of fertilizer was significant at all samplings for EC. However, moisture content was not affected significantly by amendment sources and fertilizer levels at all soil sampling. No interaction between these two factors was observed at any date for pH, EC and moisture content.

The soil pH values observed at 11.2 $Mg.ha^{-1}$ of either organic amendment did not differ from those at 22.4 $Mg.ha^{-1}$ sampled at 19, 80 and 111 days. Lowest pH values were observed for SS at both rates at the last three soil samplings.

Electrical conductivity was affected significantly by amendment sources and fertilizer levels at all four soil samplings (Table 29). Utilization of organic amendments resulted in significantly higher EC values than those for inorganic amendments. Organic amendments did not differ in EC values from each other at 19 and 111 days after application of treatments. However, at 48 and 80 days, PM at 22.4 $Mg.ha^{-1}$ had the highest EC value. Inorganic amendments did not differ from each other in EC at 48 and 80 days. At 19 and 111 days, EC at both BC rates was not statistically different but did differ from that for FO. Electrical conductivity values during the season were significantly higher with fertilizer at 2800 $kg.ha^{-1}$ than at 1400 $kg.ha^{-1}$ (Table 29).

Carbon Dioxide Evolution

Cumulative CO_2-C evolution in selected treatments was observed during 60 days of incubation (Fig. 9). Amendment sources had a

Table 29. Main effect of amendment sources and fertilizer levels on soil pH, EC and moisture when fertilizer at 1400 and 2800 kg.ha^{-1} were considered at four dates after application of treatments. Tomato experiment, 1983.

Treatments	pH	EC	Moisture	pH	EC	Moisture
		dS.m^{-1}	g.kg^{-1}		dS.m^{-1}	g.kg^{-1}
	19 days[^]			48 days[^]		
Amendment[+]						
SS (11.2 Mg.ha^{-1})	6.71bc[y]	3.30a	177	5.94	2.44b	165
SS (22.4 Mg.ha^{-1})	7.03ab	3.24a	175	6.04	2.68b	164
PM (11.2 Mg.ha^{-1})	7.00ab	3.07a	189	6.27	2.56b	171
PM (22.4 Mg.ha^{-1})	7.17a	3.30a	182	6.35	2.98a	169
BC (1.12 Mg.ha^{-1})	6.30d	2.57b	183	6.19	1.53c	174
BC (2.24 Mg.ha^{-1})	6.40cd	2.56b	198	6.39	1.45c	184
FO	6.54cd	2.19c	185	6.34	1.28c	173
F values	***	***	NS	NS	***	NS
Fert. levels (kg.ha^{-1})						
1400	6.73	2.48	185	6.21	1.69	173
2800	6.72	3.30	183	6.22	2.58	170
F values	NS	***	NS	NS	***	NS
	19 days[^]			48 days[^]		
Amendment[+]						
SS (11.2 Mg.ha^{-1})	5.83c	1.35b	113	6.11c	1.51a	125
SS (22.4 Mg.ha^{-1})	5.91bc	1.54ab	115	6.22bc	1.53a	134
PM (11.2 Mg.ha^{-1})	6.15ab	1.36b	116	6.42ab	1.48a	126
PM (22.4 Mg.ha^{-1})	6.21a	1.70a	145	6.42ab	1.55a	128
BC (1.12 Mg.ha^{-1})	6.29a	0.86c	124	6.48ab	0.91b	143
BC (2.24 Mg.ha^{-1})	6.33a	1.03c	140	6.57a	0.91b	149
FO	6.13ab	0.89c	107	6.56a	0.76c	150
F values	***	***	NS	**	***	NS
Fert. levels (kg.ha^{-1})						
1400	6.17	1.04	126	6.46	0.96	138
2800	6.07	1.45	120	6.36	1.50	135
F values	NS	***	NS	NS	***	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% level, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

[^] Days after application of treatments.

[+] See Table 20 for abbreviations.

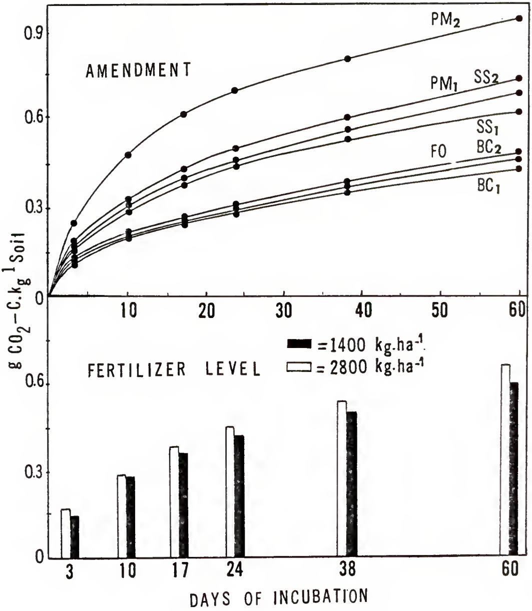

Fig. 9 Main effect of amendment and fertilizer level on cumulative CO_2-C production. Tomato experiment, 1982. See Table A-13 for abbreviations.

significant influence on the amount of CO_2-C evolved from all six treatments sampled. However, only fertilizer level had a significant influence on CO_2-C production at 38 and 60 days after the beginning of the incubation period (Table A-16).

Highest and lowest cumulative CO_2-C evolution during the incubation was observed with PM at 22.4 $Mg.ha^{-1}$ (termed PM_2) and lowest rate of BC (termed BC_1). For PM_2 soils values increased from 0.24 to 0.96 g CO_2-$C.kg^{-1}$ of dry soil at 3 and 60 days, respectively. Similarly the BC_1 values increased from 0.24 to 0.96 g CO_2-$C.kg^{-1}$ of dry soil during the same period, the PM_2 values were significantly more than from the other six amendments. Other organic amendments (SS_1, SS_2 and PM_1) formed an intermediate group in regard to cumulative CO_2-C evolved and these treatments did not differ significantly (Table A-16 and Fig. 9).

Another group comprised by FO, BC and BC_2 produced the lowest amount of cumulative CO_2-C evolution during the incubation period and did not show significant differences among them (Table A-16 and Fig. 9).

At the end of the incubation period, average means for cumulative CO_2-C evolved with organic amendments was 61% more than for average means observed with inorganic amendment sources.

With increase in fertilizer level, the CO_2-C evolved was greater during the incubation period. However, the increase was very small, although significant differences were observed at 38 and 60 days (Table A-16 and Fig. 9).

Organic Matter and Cation Exchange Capacity

Of the 21 original treatments, 11 treatments were selected for determination of OM and CEC. Both of these analyses were made at 19, 80

Table 30. Analysis of variance and treatment means for soil pH, OM and CEC at three dates after application of treatments. Tomato experiment, 1983.

Source of variation		df	pH			OM			CEC		
			Days after application of treatments								
			19	80	152	19	80	152	19	80	152
			Mean square								
Treatment		10	0.034	0.030	0.027	28.2*	25.5*	29.9*	155.6*	153.8*	155.2
Error		11	0.080	0.022	0.018	0.5	6.4	9.4	31.0	51.1	71.9
Treatments											
Amend. source$^+$	Amend. rate	Fert. level	pH, 0.5 M $CaCl_2$			OM, $g.kg^{-1}$			CEC, mmol($\frac{1}{2}$ Ca^{+2}).kg^{-1}		
	$Mg.ha^{-1}$	$kg.ha^{-1}$									
FO		2800	5.42	5.09	5.33	19.8b^y	19.3d	19.5c	37.5c	40.7d	42.1
SS	11.2	0	5.32	5.23	5.50	21.1b	21.7cd	20.1c	40.5bc	42.8cd	48.7
		2800	5.15	5.27	5.17	20.3b	22.7bcd	23.2abc	40.4bc	43.7bcd	46.7
SS	22.4	0	5.81	5.44	5.31	28.9a	28.8a	29.6ab	55.3a	58.7abcd	59.8
		2800	5.19	5.13	5.28	28.7a	28.4ab	29.9a	60.0a	61.1ab	60.0
PM	11.2	0	5.31	5.26	5.42	21.1b	21.7cd	22.6abc	57.5a	55.6abcd	54.2
		2800	5.29	5.18	5.36	21.3b	22.1cd	22.3bc	52.5ab	58.9abc	61.2
PM	22.4	0	5.47	5.43	5.47	26.4a	24.5abcd	24.5abc	60.1a	62.6a	66.7
		2800	5.57	5.38	5.28	27.3a	27.2abc	24.8abc	58.2a	61.1ab	65.1
BC	1.12	2800	5.29	5.10	5.12	20.0b	19.4d	19.5c	41.2bc	42.8cd	43.4
BC	2.24	2800	5.16	5.23	5.36	20.4b	19.2d	18.5c	48.7abc	47.6abcd	48.7

*F values significant at the 5% level.

[y] Treatment mean separation within columns by Duncan's Multiple Range Test, 5% level.

+See Table 20 for abbreviations.

and 152 days after field application of treatments. Analysis of variance and means for those treatments are shown in Table 30.

Values of pH in 0.5 M $CaCl_2$, which was the initial solution utilized to saturate the soil for CEC determination, were recorded. These values were lower than corresponding values observed with water at 19 and 80 days (Tables 6 and 30). Treatments had no significant influence on pH values at any of the three sampling dates.

Organic amendments, SS and PM at higher rate (22.4 $Mg.ha^{-1}$), with or without fertilizer, had the highest values for OM, and did not differ between each other throughout the season. The lowest OM values were obtained when inorganic amendments FO or BC were used. With all treatments, OM values remained almost constant from 19 to 152 days after application of treatments. Average mean of soil OM between organic amendments SS and PM were 24.6, 24.5 and a 24.5 $g.kg^{-1}$ at 19, 80 and 152 days, respectively. At these same dates, the average means for inorganic amendments were 20.0, 19.3 and 19.2 $g.kg^{-1}$, respectively.

Treatments had a significant influence on CEC values at 19 and 80 days. Highest values for CEC at 19 days were obtained from SS at 22.4 $Mg.ha^{-1}$, PM at 11.2 or 22.4 $Mg.ha^{-1}$, and BC at 2.24 $Mg.ha^{-1}$. Among these treatment means, no significant difference was observed. Treatment with FO, SS at 11.2 $Mg.ha^{-1}$ and BC at 1.12 $Mg.ha^{-1}$ had the lowest CEC values at 19 days. At 80 days, responses of CEC to treatments were quite similar to those observed at 19 days. In all treatments the CEC increased slightly with time after treatment was applied. The average means for CEC with organic amendments were 53.0, 55.5 and 58.0 mmol ($^1/_2$ Ca^{+2}).kg^{-1}, at 19, 80 and 152 days, respectively. With inorganic amendments, these corresponding average means for CEC were

41.2, 42.9 and 44.0 mmol $(\frac{1}{2}Ca^{+2}).kg^{-1}$ at the same three dates, respectively.

Ion Concentration in Water Extract

Analysis of variance and significant contrasts for Ca, Mg, K and Cl in water are shown in Tables A-17 and A-18. Means for these elements obtained from organic amendment sources are shown in Table 31.

Soluble Ca concentrations extracted from soil with SS and PM at 48 and 111 days were significantly higher at the higher amendment rate. The interaction between amendment rates and fertilizer level was significant at 48 days for both SS and PM treatments. However, soluble Ca had a significant linear and positive trend for both rates of SS and a quadratic trend for PM with increase in the level of fertilizer used. At 111 days, interaction was observed only at both rates of SS; quadratic responses to level of fertilizer added were found. At the same date, the main effect of fertilizer with PM amendments was significant and the responses were linear and quadratic (Tables A-18 and 31).

Soluble Mg concentrations for both amendment sources at all four sampling dates, except for SS at 19 days, were significantly higher with 22.4 $Mg.ha^{-1}$ than with 11.2 $Mg.ha^{-1}$. At 19, 48, 80 and 111 days, interaction between amendment rate and fertilizer level was significant for SS. Except at 48 days, soluble Mg concentration for both rates of SS had a significant linear positive trend to fertilizer levels. However, at 80 days with SS, a significant quadratic response for both rates were observed (Tables A-18 and 31).

With PM treatment, a significant linear positive main effect of fertilizer level on Mg concentration was observed at 48 and 111 days.

Table 31. Effects of organic amendment sources and rate and of fertilizer levels in water extracted soil Ca, Mg, K and Cl concentration at four dates after application of treatments. Tomato experiment, 1983.

	Sewage sludge						Poultry manure					
	11.2 Mg.ha^{-1}			22.4 Mg.ha^{-1}			11.2 Mg.ha^{-1}			22.4 Mg.ha^{-1}		
	Fertilizer level (kg.ha^{-1})											
Time	0	1400	2800	0	1400	2800	0	1400	2800	0	1400	2800
Days	Ca, mg.kg^{-1}											
19	18	22	24	28	23	23	22	22	53	35	35	32
48	21	59	144	110	141	118	50	78	142	162	158	123
80^{+}	-	-	-	-	-	-	-	-	-	-	-	-
111	77	68	128	166	172	136	40	61	67	71	106	134
	Mg, mg.kg^{-1}											
19	5	7	10	8	7	6	6	6	6	9	9	10
48	17	32	52	56	50	69	23	26	33	32	48	51
80	47	45	49	55	70	48	38	41	33	38	48	34
111	6	14	18	17	23	25	8	12	17	5	13	11
	K, mg.kg^{-1}											
19	39	87	69	51	59	90	68	79	170	177	217	234
48	128	148	155	133	127	189	152	196	221	225	360	373
80	40	107	97	68	107	142	165	147	213	193	388	283
111	86	103	116	100	96	94	93	97	115	121	159	186
	Cl, mg.kg^{-1}											
19	45	89	116	72	112	145	57	75	156	100	183	221
48	29	70	66	45	71	92	47	72	121	63	150	152
80	14	67	66	36	64	91	30	58	92	50	128	130
111	23	56	71	42	54	64	22	46	83	52	77	93

$^{+}$Values for Ca concentration at 80 days were not determined.

At 80 days, the interaction was significant and a quadratic trend to fertilizer level was found at both rates of PM.

Soluble K concentration at all four samplings for PM soil was significantly higher with 22.4 $Mg.ha^{-1}$ than 11.2 $Mg.ha^{-1}$. For SS treatment, the main effect of fertilizer was significantly linear at all soil samplings. However, in soil with the PM, the main effect of fertilizer was significantly quadratic to fertilizer level at the four samplings. An interaction between amendment rate and fertilizer level for K extracted was significant for SS at 19, 48 and 111 days and for PM at all soil samplings (Tables A-18 and 31).

Soluble Cl at the first three dates for SS and at all soil samplings for PM soil treatments was significantly different between both amendment sources. At all soil samplings, Cl values had a significant linear main effect of fertilizer level for both SS and PM. However, at 19, 48 and 80 days, interaction effect for soil Cl was found between PM rate and fertilizer level (Tables A-18 and 31).

Mean values obtained from inorganic amendment at four dates after application of treatments are shown in Table 32.

Soluble Ca concentration at 19 and 48 days, when FO was used, had a significant quadratic effect with increase in the fertilizer level. At 19 days for BC, interaction between amendment rate and fertilizer level was significant. At 48 days, main effect of fertilizer was significant when combined with BC. At each sampling, BC rate did not affect Ca level extracted (Tables A-18 and 32).

Soluble Mg, when FO was used, had a significant quadratic response with increase in the fertilizer level. For BC, a significant difference was found between rates at 19 and 80 days. At 19 days, for BC

Table 32. Effects of inorganic amendment sources and rate and of fertilizer levels on water extractable soil Ca, Mg, K and Cl concentration at four dates after application of treatments. Tomato experiment, 1983.

	Fertilizer only			Bentonite clay					
				1.12 Mg.ha^{-1}			2.24 Mg.ha^{-1}		
	Fertilizer level								
Time	1400	2800	4200	1400	2800	4200	1400	2800	4200
Days					Ca, mg.kg^{-1}				
19	56	61	160	69	112	85	85	67	91
48	12	14	135	52	73	83	62	69	105
80	-	-	-	-	-	-	-	-	-
111	16	17	25	34	51	50	32	43	58
					Mg, mg.kg^{-1}				
19	14	15	37	24	27	22	13	18	26
48	20	15	27	8	16	25	15	14	22
80	19	22	18	40	43	37	24	28	29
111	7	4	7	27	19	29	50	23	28
					K, mg.kg^{-1}				
19	67	79	127	54	105	117	59	97	139
48	119	119	151	118	129	132	134	149	152
80	67	65	108	78	116	110	65	119	136
111	84	86	90	85	87	93	92	99	133
					Cl, mg.kg^{-1}				
19	69	90	181	67	105	135	74	97	134
48	44	60	101	54	79	106	40	67	123
80	40	41	96	32	43	60	46	53	61
111	22	35	50	31	43	51	31	54	38

treatment, interaction between amendment rate and fertilizer level was significant. At 48 days, the only statistical significance in Mg level was a linear main effect of fertilizer level when BC was applied (Tables A-18 and 32).

Soluble K concentration had significant quadratic trends when rates of FO were applied at the first two samplings. At 80 days, this trend was linear and at 111 days was not significant. When BC was the amendment, only at 48 days did the rate become significantly different. However, at all soil samplings, the main effect of fertilizer on soluble K concentration was a significant linear effect (Tables A-18 and 32).

Soluble Cl had a quadratic response to FO rates at 19 and 80 days. However, at 48 and 111 days, a linear significant response was observed. When soil received BC, at the first two samplings, Cl concentration response to fertilizer level was linear. At the last two samplings, the response to fertilizer was quadratic (Tables A-18 and 32).

Ion Concentration in Mehlich I Extract

Analysis of variance and means for the effect of amendment sources and rates, and of fertilizer levels on macronutrient concentrations in Mehlich I soil extract at four dates after application of treatments are shown in Tables A-19 and 33, respectively.

The Ca level differed between SS amendment rates at all four samplings. However, for PM, only at the first and last samplings did Ca differ significantly with amendment rate. Quadratic response for mean effect of fertilizer level was observed for Ca extracted at 19, 80 and 111 days. However, at 19 and 111 days, interaction was significant between PM rate and fertilizer level (Tables A-20 and 33).

Table 33. Effects of organic amendment sources and rate and of fertilizer level on mean macronutrient concentration in Mehlich I soil extract at four dates after application of treatments. Tomato experiment, 1983.

	Sewage sludge						Poultry manure					
	11.2 Mg.ha^{-1}			22.4 Mg.ha^{-1}			11.2 Mg.ha^{-1}			22.4 Mg.ha^{-1}		
	Fertilizer level (kg.ha^{-1})											
Time	0	1400	2800	0	1400	2800	0	1400	2800	0	1400	2800
Days							Ca, mg.kg^{-1}					
19	1473	1346	1376	2133	1677	1434	1975	1882	1668	1940	3302	2814
48	1250	1506	1529	1970	1914	1602	2502	2201	2042	1913	2328	2566
80	1362	1254	1400	2049	1673	1766	2085	2302	2382	2143	2599	2280
111	1408	1365	1320	2000	1590	1718	1848	2030	1621	1880	2280	2215
							Mg, mg.kg^{-1}					
19	186	215	232	318	282	274	216	185	216	203	320	227
48	134	211	193	338	302	343	199	189	186	203	252	210
80	156	210	207	208	291	287	189	185	217	186	241	195
111	188	196	193	288	240	272	188	176	183	241	237	226
							K, mg.kg^{-1}					
19	175	224	207	218	254	266	303	263	438	342	646	697
48	47	139	86	95	99	218	142	220	298	221	428	658
80	124	245	240	208	268	295	325	323	444	395	454	492
111	43	63	107	66	84	96	54	84	135	153	218	337
							P, mg.kg^{-1}					
19	332	321	291	219	289	268	162	352	409	252	251	397
48	237	258	233	134	258	255	228	304	293	271	265	334
80	294	269	248	254	296	286	285	315	444	340	303	449
111	245	264	290	117	280	287	252	341	306	310	337	395

Magnesium concentration in soil with SS was significantly higher with 22.4 $Mg.ha^{-1}$ than at 11.2 $Mg.ha^{-1}$. With PM, this response was observed only at 80 days. Interaction between SS amendment rate and fertilizer level was significant at the first three soil samplings, and for PM at the first two samplings (Tables A-20 and 33).

Potassium concentration in these extracts was not affected by SS rates. However, PM rates had significantly higher values for K at 22.4 $Mg.ha^{-1}$ than at 11.2 $Mg.ha^{-1}$ at all soil samplings. At the last three samplings, the use of SS resulted in a significant linear positive trend for K for the main effect of fertilizer. Significant linear main effect of fertilizer level on K response was observed for PM at all soil samplings. However, the interaction between PM amendment rate and fertilizer level was significant for K values at 19, 48 and 111 days. At 19 days, both PM rates showed quadratic trends to fertilizer level, but at 48 and 111 days this trend was linear (Tables A-20 and 33).

Phosphorus concentrations had few significances for both amendment sources and most of them were at the 5% level of significance. Rate of SS interaction with fertilizer on P level was significant at 48 days. For PM, the main effect of fertilizer was linear at 80 and 111 days, P concentration increased with increase in the level of fertilizer applied (Tables A-20 and 33).

Means of inorganic amendment sources and rates and of fertilizer levels for macronutrients on Mehlich I soil extract are shown in Table 34. When F0 was applied, level of Ca extracted had a significant quadratic response at 48 days and linear response to fertilizer rate was observed at 48 days. At 80 days, this response was linear (Tables A-20 and 34).

At the three first samplings, the two rates of BC were statistically different in Ca extracted and its higher BC rate gave higher Ca concentration. For soil with BC, at 19 and 48 days, the main effect of fertilizer was a significant quadratic response in Ca concentration (Tables A-20 and 34).

Magnesium concentration in soil extracted by Mehlich I was affected significantly by BC rates at the three first samplings. Bentonite clay at 2.24 $Mg.ha^{-1}$ had much more Mg than at 1.12 $Mg.ha^{-1}$. Also for BC, at 48 and 80 days, main effect of fertilizer had a significant quadratic trend (Tables A-20 and 34).

Potassium concentration at 19 and 111 days, when FO was utilized, had a significant quadratic response to increase in the fertilizer levels from 1400 to 4200 $kg.ha^{-1}$. At these dates the K concentration for BC at 2.24 $Mg.ha^{-1}$ was significantly higher than for BC at 1.12 $Mg.ha^{-1}$. At 19, 48 and 111 days for BC, the main effect of fertilizer was a significant linear positive effect for K concentration with increase in level of fertilizer utilized (Tables A-20 and 34).

Phosphorus concentrations at 80 and 111 days were significantly affected by fertilizer levels when FO was used. At 80 days, fertilizer effect had a significant linear positive trend for P concentration. However, at 111 days, a quadratic trend was observed. When BC was used, the only significance observed was between rates at 80 days, the higher rate gave higher P concentration (Tables A-20 and 34).

Statistical analysis for the effects of amendment sources and rates and of fertilizer levels on Cd, Ni, Mn, Fe, and Zn concentration in Mehlich I extract at four dates after application of treatments are

Table 34. Effects of inorganic amendment sources and rate and of fertilizer level on mean macronutrient concentration in Mehlich I extract at four dates after application of treatments. Tomato experiment, 1983.

	Fertilizer only			Bentonite clay					
				1.12 Mg.ha^{-1}			2.24 Mg.ha^{-1}		
	Fertilizer level								
Time	1400	2800	4200	1400	2800	4200	1400	2800	4200
Days					Ca, mg.kg^{-1}				
19	1540	1490	1770	1430	1360	1110	1440	2180	1720
48	1690	1640	2290	1250	1490	1320	1550	2330	1840
80	1980	1340	1250	1140	1310	1240	1370	1670	1700
111	1360	1370	1470	1370	1250	1230	1350	1380	1620
					Mg, mg.kg^{-1}				
19	174	153	195	135	151	152	166	185	192
48	171	134	183	131	155	137	151	227	187
80	132	122	135	141	141	127	139	210	168
111	145	145	133	127	124	127	132	147	138
					K, mg.kg^{-1}				
19	232	215	461	191	228	254	211	308	317
48	155	146	171	52	140	151	136	227	215
80	219	198	296	168	298	229	227	210	255
111	57	153	85	49	65	76	69	62	156
					P, mg.kg^{-1}				
19	233	338	276	291	335	278	284	239	268
48	219	286	274	235	220	233	189	171	209
80	203	298	314	259	327	283	194	220	272
111	229	305	301	280	302	286	235	276	294

shown in Table A-20. In Table 35 are shown concentration means of these five elements in Mehlich I extract when SS and PM were applied.

Average Cd concentration for soil with SS was 1220 $\mu g.kg^{-1}$ compared to an average for PM of 50 $\mu g.kg^{-1}$. Highest Cd value of 1903 $\mu g.kg^{-1}$ was observed with 22.4 $Mg.ha^{-1}$ of SS combined with 2800 $kg.ha^{-1}$ of fertilizer for soil sampled at 48 days after application of treatments. The lowest Cd value for SS was 340 $\mu g.kg^{-1}$ observed after 111 days when no fertilizer was applied. Only for SS did the Cd concentration become significantly affected by treatments. At all four samplings, Cd was statistically higher at the higher SS rate. At all soil samplings, the main effect of fertilizer level combined with SS was a significant linear positive trend for Cd. However, except for 19 days, the interaction between amendment rates and fertilizer levels was significant (Tables A-21 and 35).

Average Ni concentration for SS treatment was 1970 $\mu g.ha^{-1}$ and for PM this average was 301 $\mu g.kg^{-1}$. Highest Ni value of 2870 $\mu g.kg^{-1}$ was observed at 111 days when SS at 22.4 $Mg.ha^{-1}$ was combined with fertilizer at 2800 $kg.ha^{-1}$. The lowest Ni concentration for SS was 1000 $\mu g.kg^{-1}$ observed at 111 days when no fertilizer was used. As observed for Cd, Ni concentration was only significantly affected when SS was applied. This effect of SS rate was found at all four samplings and was statistically different between them. The higher SS rate always gave the higher Ni concentration. At 19 and 80 days, the interaction effect for Ni between SS rate and fertilizer level was significant (Tables A-21 and 35).

Manganese concentration in soil extract increased with increase in SS or PM rates. For SS, a significant difference between rates was

Table 35. Effects of organic amendment sources and rates and of fertilizer level of Cd, Ni, Mn, Fe and Zn concentration in Mehlich I extract at four dates after application of treatments. Tomato experiment, 1983.

	Sewage sludge						Poultry manure					
	11.2 $Mg.ha^{-1}$			22.4 $Mg.ha^{-1}$			11.2 $Mg.ha^{-1}$			22.4 $Mg.ha^{-1}$		
	Fertilizer level ($kg.ha^{-1}$)											
Time	0	1400	2800	0	1400	2800	0	1400	2800	0	1400	2800
Days	Cd, $\mu g.kg^{-1}$											
19	726	816	1200	1320	1410	1540	47	45	28	26	38	35
48	276	1060	891	1900	1420	1900	50	50	50	50	50	50
80	843	1460	1290	1640	1440	1870	70	61	74	68	51	65
111	340	613	713	1440	1430	1840	48	48	48	48	48	48
	Ni, $\mu g.kg^{-1}$											
19	1350	1200	1830	1880	2030	2230	192	128	124	113	84	108
48	1000	1330	1500	2000	2170	2830	500	500	500	500	500	500
80	2290	2460	1980	1800	2000	2100	343	363	403	390	303	316
111	1700	2000	1750	2710	2390	2870	480	480	480	480	480	480
	Mn, $mg.kg^{-1}$											
19	8.3	8.8	11.0	11.0	10.1	11.2	10.5	9.6	8.6	8.9	11.3	10.4
48	3.5	7.3	7.7	9.7	8.3	9.2	8.4	7.3	8.4	7.3	9.2	3.4
80	5.2	5.9	6.0	8.1	6.6	7.0	7.1	5.9	5.7	5.4	8.1	7.8
111	4.5	4.5	4.7	6.4	5.3	5.7	4.2	4.5	4.8	4.8	6.3	6.8
	Fe, $mg.kg^{-1}$											
19	46	41	38	37	38	34	26	38	35	35	37	47
48	62	53	43	28	44	47	39	42	44	35	42	46
80	50	46	40	22	45	42	37	39	38	38	39	39
111	48	41	47	19	49	44	35	41	42	35	30	39
	Zn, $mg.kg^{-1}$											
19	20	25	25	31	33	34	7	6	7	8	10	9
48	17	20	33	33	36	37	5	6	7	9	7	9
80	12	25	25	30	29	24	5	6	8	6	7	8
111	20	13	26	23	25	38	7	5	6	5	10	10

observed at all soil samplings. For soil with PM, only at the last two samplings was a significant difference between rate detected. Interaction in Mn level between SS amendment rates and fertilizer level was observed at 19 and 48 days and a similar effect on Mn extracted was noted at 19 and 80 days for PM amendment (Tables A-21 and 36).

Iron concentrations in soil extracted with Mehlich I were greater than concentrations of Mn and Zn. Statistical significance between amendment rates was observed for Fe values at 48 and 80 days for SS and only at 19 days with PM. In general, the higher rate gave higher Fe values. For SS, interaction effect between amendment rate and fertilizer level was significant for Fe at the last three samplings (Tables A-21 and 36).

As observed for Cd and Ni, the Zn concentrations in the soil receiving when SS, were much greater than those with other amendment sources. Significant difference in Zn extracted between SS rates was observed at all soil sampling dates. With SS at 22.4 $Mg.ha^{-1}$, higher Zn concentration was found. At the last three samplings, the interaction between SS rates and fertilizer level was significant (Tables A-21 and 36).

Significant contrasts and means for Cd, Ni, Mn, Fe and Zn in Mehlich I soil extract, when inorganic amendments were used, are shown in Tables A-21 and 36, respectively.

Statistically significant difference for Cd and Ni concentration in soil was not observed between treatments when FO or BC were used. Average Cd and Ni concentrations, when FO was added, were 52 and 505 $\mu g.kg^{-1}$, respectively. For BC, these averages were 48 and 420 $\mu g.kg^{-1}$ for Cd and Ni, respectively. These two averages were significantly

Table 36. Effects of inorganic amendment source and rate and of fertilizer levels on Cd, Ni Mn, Fe and Zn concentration in Mehlich I extract at four dates after application of treatments. Tomato experiment, 1983.

	Fertilizer only			Bentonite clay					
				1.12 Mg.ha^{-1}			2.24 Mg.ha^{-1}		
	Fertilizer level								
Time	1400	2800	4200	1400	2800	4200	1400	2800	4200
Days					Cd, μg.kg^{-1}				
19	51	55	57	27	39	17	62	22	31
48	50	50	50	50	50	50	50	50	50
80	66	63	68	73	69	42	68	45	80
111	40	40	31	39	48	39	48	48	48
					Ni, μg.kg^{-1}				
19	474	441	522	131	193	129	325	470	520
48	500	505	500	500	500	500	500	500	500
80	340	370	486	370	393	376	440	396	456
111	643	643	643	480	480	480	480	480	480
					Mn, mg.kg^{-1}				
19	9.4	8.4	9.7	4.3	4.0	4.2	4.0	3.9	3.7
48	7.5	6.4	8.2	7.3	7.4	7.3	7.9	7.4	8.9
80	6.7	5.2	6.3	5.4	5.4	5.4	6.1	6.0	7.1
111	5.2	5.0	5.1	4.0	3.8	4.3	3.8	3.5	5.7
					Fe, mg.kg^{-1}				
19	26	39	42	79	83	85	90	100	98
48	36	55	51	43	44	42	36	39	41
80	34	48	41	43	40	44	36	30	34
111	36	46	51	43	49	50	43	44	40
					Zn, mg.kg^{-1}				
19	15	15	22	4	4	6	7	6	7
48	10	22	22	7	6	6	6	7	7
80	45	63	15	5	5	4	6	6	6
111	7	13	18	6	9	5	6	5	6

lower than those observed for SS at all soil samplings (Tables A-21, 35 and 36).

Manganese concentrations were not affected significantly when FO was utilized. When BC was used, soil extract Mn at 80 and 111 days gave significant differences between rate and also had a significant quadratic main effect of fertilizer level, respectively (Tables A-21 and 36).

Both Fe and Zn concentrations had a significant linear positive trend at 19 and 111 days when FO was applied. However, at 48 and 80 days, a quadratic trend in both Fe and Zn values were observed. Significant changes in Fe and Zn concentrations was not observed when BC amendment was used (Tables A-21 and 36).

Tissue Analysis

Nutrient Concentration in Leaf and Fruit

Amendment sources and rate and fertlizer level effects on leaf tissue macronutrients at three dates after transplant are shown in Table A-22.

Means of metals for leaf macronutrients from organic amendments at two rates combined with three fertilizer levels are shown in Table 37. Phosphorus and Ca concentrations were not affected by treatments at all soil samplings (Table A-22). However, concentrations of N, K and Mg were significantly affected.

Total N concentrations on tomato leaf were significantly higher at 22.4 $Mg.ha^{-1}$ than at 11.2 $Mg.ha^{-1}$ for both SS and PM amendments, at 63 and 93 days after transplant. For SS, the average N concentration was 37.9 $g.kg^{-1}$ at the lower rate and 40.8 $g.kg^{-1}$ at the higher one. For PM, the average N concentration was 39.6 and 46.5 $g.kg^{-1}$ at the lower

Table 37. Effect of organic amendment sources and rate and of fertilizer levels on macronutrient concentrations of leaf tissue at three dates after transplant. Tomato experiment, 1983.

	Sewage sludge						Poultry manure					
	11.2 $Mg.ha^{-1}$			22.4 $Mg.ha^{-1}$			11.2 $Mg.ha^{-1}$			22.4 $Mg.ha^{-1}$		
	Fertilizer level ($kg.ha^{-1}$)											
Time	0	1400	2800	0	1400	2800	0	1400	2800	0	1400	2800
Days	N, $g.kg^{-1}$											
41	40.5	40.2	40.9	41.9	41.3	42.8	41.8	44.0	42.6	39.9	41.4	43.2
63	42.6	44.1	43.8	46.8	45.2	46.5	42.9	46.0	44.0	45.7	46.0	46.9
93	26.0	30.2	32.4	30.6	37.2	35.0	28.3	31.4	35.8	36.7	36.7	39.2
	P, $g.kg^{-1}$											
41	9.00	9.76	9.23	10.23	8.73	8.83	8.20	9.23	8.96	7.55	9.13	7.73
63	7.93	7.70	6.83	7.83	8.66	7.50	7.40	8.36	9.00	8.30	8.26	7.50
93	6.46	6.23	7.23	6.03	5.86	7.36	6.20	5.52	5.63	5.73	5.50	5.43
	K, $g.kg^{-1}$											
41	31.1	28.7	30.7	29.2	29.9	30.8	29.5	28.2	27.5	28.8	28.3	29.8
63	30.4	27.0	27.8	27.3	23.9	29.4	33.3	36.4	36.6	35.5	33.7	34.5
93	7.8	7.3	10.1	11.9	11.3	10.6	15.4	18.2	24.2	24.4	25.4	26.0
	Ca, $g.kg^{-1}$											
41	10.30	9.20	11.50	7.60	7.76	11.16	9.87	10.66	8.00	10.00	8.00	9.20
63	7.14	8.04	7.91	7.90	9.75	7.35	8.70	11.12	8.04	6.79	7.70	7.45
93	11.29	15.09	13.00	11.98	13.85	15.26	12.29	14.12	13.09	8.13	10.12	10.25
	Mg, $g.kg^{-1}$											
41	3.16	3.97	4.66	3.66	4.02	3.67	3.40	3.75	2.90	3.92	3.56	3.95
63	5.07	6.16	6.06	5.43	6.25	6.35	5.12	5.30	4.60	4.66	4.80	4.75
93	5.50	5.93	6.41	6.60	7.25	7.91	4.91	4.55	4.26	4.66	5.03	4.88

and higher rate, respectively. With all treatments, leaf N concentration increased from 41 to 63 days and after that it decreased. Poultry manure when compared with SS at the same rate and fertilizer level had slightly more N in the leaf. For SS at 93 days and PM at 41 and 93 days, the main effect of fertilizer level was a significant linear positive response for N concentration on tomato leaf (Tables A-22 and 37).

Potassium concentration of leaf tissue from soil when organic amendments were used had few significant effects. At 63 days, interaction between SS amendment rate and fertilizer levels was significant. At 93 days, PM rates significantly affected K level and the main effect of fertilizer levels was a significant linear positive trend (Tables A-22 and 37).

Magnesium concentrations of tomato leaf were significantly affected when SS was applied. At 93 days, tissue from both SS rates differed in Mg content from each other. At all three samplings, the main effect of fertilizer was a significant linear Mg response with increase in the level of fertilizer. However, at 41 days, the interaction effect on Mg concentration was significant. In this case, the main effect of fertilizer should not be considered. When PM was applied, Mg concentrations in the leaf tissue were not significantly affected by amendment rate and fertilizer level (Tables A-22 and 37).

When inorganic amendments were used, macronutrient concentrations on tomato leaf are shown in Table 37. For both FO and BC treatments, the tissue N concentration had lower values than those observed with SS and PM, especially at the higher rate (Tables 37 and 38). The average N concentration for FO was 35.1 $g.kg^{-1}$ and for added BC was 35.2 $g.kg^{-1}$.

When FO was applied, the N concentration of leaf tissue had significant quadratic and linear trends with fertilizer level at 41 and 63 days, respectively. When BC was applied, at all leaf samplings, the main effect of fertilizer level on N concentration was a significant linear positive trend and no interaction was observed (Tables A-22 and 38).

Potassium concentration of leaf, only at 41 days, was affected significantly when FO was applied. At this time, with increase of fertilizer level, the K concentration in the leaf increased linearly. Where BC was applied, at the last two samplings was there a significant difference between BC rates. Also with BC at 41 and 63 days, the main effect of fertilizer was a quadratic response for K concentration with increase in fertilizer level applied (Tables A-22 and 38).

Magnesium concentration was not influenced significantly by rates of FO utilized. For BC treatment, the only significance observed was at 41 days where the main effect of fertilizer additions had significant linear and quadratic responses (Tables A-22 and 38).

In order to compare all four amendment sources, two rates of SS, PM, BC, and FO at 1400 and 2800 kg^{-1} of fertilizer were selected. Analysis of variance and main effect of these amendment sources and fertilizer levels on N, K, and Mg concentration of tomato leaf are shown in Table 39. Data about P and Ca concentrations were omitted because no significant differences due to treatment were observed.

At all leaf samplings, the highest N concentration was observed with PM at 22.4 $Mg.ha^{-1}$. This treatment was significantly different from PM at 11.2 $Mg.ha^{-1}$ or from SS at 22.4 $Mg.ha^{-1}$, at the first two and at all leaf samplings, respectively. Throughout the season, these three

Table 38. Effect of inorganic amendment source and rate and of fertilizer level on macronutrient concentrations on tomato leaf tissue at three dates after transplant. Tomato experiment, 1983.

	Fertilizer only			Bentonite clay					
				1.12 Mg.ha^{-1}			2.24 Mg.ha^{-1}		
	Fertilizer level								
Time	1400	2800	4200	1400	2800	4200	1400	2800	4200
Days					N, g.kg^{-1}				
41	37.5	41.8	40.9	37.7	41.1	40.5	39.9	40.8	41.5
63	36.9	38.1	42.6	38.2	41.3	38.7	38.0	39.5	44.6
93	26.6	26.2	26.0	23.5	26.3	27.7	22.0	23.5	28.8
					P, g.kg^{-1}				
41	7.83	8.66	9.33	7.46	8.53	8.63	8.50	8.20	9.00
63	7.00	7.06	7.66	7.36	9.36	8.93	8.03	8.56	7.80
93	6.06	6.06	6.03	6.03	6.50	6.66	6.20	6.20	6.20
					K, g.kg^{-1}				
41	26.7	30.9	30.8	25.6	30.6	28.9	28.0	29.8	27.4
63	31.3	34.0	35.4	30.6	32.7	34.8	34.7	35.6	36.7
93	19.6	15.6	17.9	15.1	17.8	17.9	15.8	24.9	22.8
					Ca, g.kg^{-1}				
41	8.78	8.74	8.54	10.42	14.20	12.04	9.33	10.33	8.08
63	7.28	7.66	8.87	7.54	7.04	7.23	7.44	7.25	7.35
93	14.91	16.66	10.29	13.00	9.00	14.28	12.16	10.75	11.35
					Mg, g.kg^{-1}				
41	3.85	3.74	3.65	4.45	3.52	3.70	4.03	2.96	3.61
63	4.76	4.61	5.35	4.29	4.75	4.55	4.62	4.68	5.20
93	4.38	4.10	4.08	4.27	3.88	4.32	4.53	4.17	4.51

Table 39. Analysis of variance and main effect of amendment sources and fertilizer levels on N, K and Mg concentration on tomato leaf at three dates after transplant. Tomato experiment, 1983.

Source of variation	df	N			K			Mg		
		Days after transplant								
		41	63	93	41	63	93	41	63	93
		Mean square								
Block	2	1.5	4.3	9.2	13.0	17.9	66.4***	0.42	2.21***	2.60
Amendment (A)	6	13.5**	84.9***	206.0***	4.4	84.9***	210.3***	0.62**	3.32***	10.15***
Fert. levels (F)	1	27.0**	9.5	24.3*	45.8*	36.5*	60.4*	1.00*	0.04	0.03
AxF	6	5.1	5.2	7.2	5.6	5.1	28.5	0.40	0.16	0.28
Error	26	3.3	3.4	5.8	6.5	8.2	9.6	0.16	0.24	0.30
Amendment^{+}		g.kg^{-1}								
SS (11.2 Mg.ha^{-1})		40.5bc	44.0b	31.3c	29.7	27.4c	8.7d	4.3a	6.1a	6.1b
SS (22.4 Mg.ha^{-1})		42.1ab	45.8ab	36.1ab	30.3	26.6c	11.0d	3.8abc	6.3a	7.5a
PM (11.2 Mg.ha^{-1})		43.5a	45.0ab	33.6bc	27.8	36.5a	21.3b	3.3c	4.9b	4.4cd
PM (22.4 Mg.ha^{-1})		42.5ab	46.4a	38.0a	29.1	34.1ab	25.7a	3.7bc	4.8b	4.9cd
BC (1.12 Mg.ha^{-1})		39.4c	39.2c	24.9de	28.1	31.6b	16.4c	3.6bc	4.5b	4.0d
BC (2.24 Mg.ha^{-1})		39.3c	38.8c	22.7e	28.9	35.1ab	20.3b	3.5bc	4.6b	4.3cd
FO		39.7c	37.5c	26.4de	28.8	32.5b	17.6bc	3.8abc	4.7b	4.2cd
F values		**	***	***	NS	***	***	*	***	***
Fert. level (kg.ha^{-1})										
1400		40.0	41.9	29.6	27.9	31.0	16.1	3.6	5.1	5.1
2800		42.0	42.9	31.2	30.0	33.0	18.5	3.9	5.1	5.0
F values		**	NS	**	*	*	*	*	NS	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.
$^{+}$See Table 20 for abbreviations.

above treatments were statistically different in tissue N compared to that where BC or FO was used. No significant difference in total leaf N among inorganic amendments was found during the tomato cropping season (Table 39). Average N concentrations in tomato leaf for organic amendments were 42, 45 and 35 $g.kg^{-1}$ of dry tissue at 41, 63 and 93 days, respectively. At these dates, inorganic amendments had an average N of 39, 38 and 25 $g.kg^{-1}$, respectively.

With increase in the fertilizer level, the leaf N content also increased. At 41 and 93 days, fertilizer at 2800 $kg.ha^{-1}$ had higher significant N concentration in tomato leaf than at 1400 $kg.ha^{-1}$ (Table 39).

Potassium concentration in the leaf was not affected significantly by treatments at 41 days after transplant. At 63 days, PM at both rates did not differ from BC at 2.24 $Mg.ha^{-1}$. However, PM at the lower rate had the highest K concentration in leaf tissue; the lowest concentration at this time was observed for SS at both rates. At 93 days, PM at 22.4 $Mg.ha^{-1}$ gave the highest K concentration and this was statistically different from the other treatments. As observed above, at 63 days, the lowest K concentration was observed when SS at both rates was applied (Table 39). Fertilizer levels had a significant effect on K concentration in leaf at all sampling dates. Fertilizer applied at 2800 $kg.ha^{-1}$ had higher leaf K concentration than did fertilizer at 1400 $kg.ha^{-1}$ (Table 39).

Magnesium concentration of leaf tissue at all samplings, except for SS at 93 days, did not show statistical significance between rates for the same amendment source. Sewage sludge always had higher leaf Mg concentration than did other amendments and, at the last two leaf samplings, both rates of SS gave statistically different Mg levels than from the other five treatments. Fertilizer level main effect was significant at 41 days. However, at the last two samplings, Mg concentration of leaf tissue was not affected by fertilizer levels (Table 39).

Analysis of variance mean squares for micronutrients and Cd concentration in leaf at three dates after application of treatment are shown in Tables A-23. Significant contrast effects are given in Table A-24. Means for these elements when organic amendments were used are shown in Table 40.

Cadmium concentrations in tomato leaf ranged from 1.66 to 7.33 $mg.kg^{-1}$ of dry weight for SS and 0.48 to 0.75 $mg.kg^{-1}$ for PM. With increase in the SS rate used, the level of Cd in leaf also increased. Significant difference between SS rates was observed at all leaf samplings. However, PM at both rates gave quite similar leaf Cd concentration. At all leaf samplings, the average Cd value for SS was significantly higher than that observed for PM (Tables A-24 and 40). When fertilizer was applied in combination with SS rates, the Cd concentration had a significant linear increase for main effect of fertilizer level at all sampling dates.

Manganese concentration in leaf increased from 41 to 93 days after transplant for both organic amendments. Significant difference between amendment rates was observed only at 41 days for PM and at 93 days for SS treatments. However, significant linear main effect of fertilizer level for both organic sources was observed at 41 and 93 days. Interaction between PM amendment rate and fertilizer levels was also significant at 63 days, but for SS this interaction effect was

Table 40. Effects of organic amendment sources and rates and of fertilizer level on mean values for tomato leaf micronutrients and Cd concentrations at three dates after transplant. Tomato experiment, 1983.

	Sewage sludge						Poultry manure					
	11.2 $Mg.ha^{-1}$			22.4 $Mg.ha^{-1}$			11.2 $Mg.ha^{-1}$			22.4 $Mg.ha^{-1}$		
	Fertilizer level ($kg.ha^{-1}$)											
Time	0	1400	2800	0	1400	2800	0	1400	2800	0	1400	2800
Days	Cd, $mg.kg^{-1}$											
41	4.88	5.00	5.81	4.91	6.58	7.31	0.58	0.75	0.50	0.50	0.48	0.66
63	1.66	2.66	3.08	2.41	3.16	3.58	0.50	0.50	0.50	0.50	0.50	0.50
93	2.55	4.25	6.16	4.58	6.25	7.33	0.50	0.58	0.50	0.50	0.58	0.60
	Mn, $mg.kg^{-1}$											
41	87	94	91	69	82	101	59	71	73	62	80	89
63	135	138	161	143	167	152	182	143	182	159	187	180
93	222	244	400	279	352	408	261	258	335	256	260	315
	Fe, $mg.kg^{-1}$											
41	143	132	142	170	158	184	124	171	173	184	131	140
63	83	88	83	92	97	98	95	95	85	88	85	85
93	109	72	84	91	80	81	89	116	121	111	89	101
	Zn, $mg.kg^{-1}$											
41	43	60	58	52	65	63	26	27	44	26	35	36
63	42	48	60	54	63	56	38	29	34	35	37	28
93	26	25	37	43	43	40	39	30	37	31	28	34
	Cu, $mg.kg^{-1}$											
41	9.2	9.9	10.5	11.3	10.1	14.5	6.1	6.0	6.9	6.7	7.4	7.6
63	10.9	11.6	11.4	10.9	12.6	12.5	8.3	9.2	7.5	8.5	9.1	8.8
93	7.9	10.5	11.9	14.4	13.1	11.9	8.8	6.8	7.8	8.3	8.2	8.4

significant at both 41 and 93 days. At all leaf samplings, the highest average Mn concentration was found when SS was used and was significantly higher than observed for PM (Tables A-24 and 40).

Iron concentration in leaf, when PM was used, had significant interaction between PM rate and fertilizer level at 41 and 93 days. However, when SS was utilized, statistical difference between amendment rates and significant quadratic main effect for fertilizer level were observed. Only at the last leaf sampling did the average Fe concentration for leaf tissue from PM exceed that from SS (Tables A-24 and 40).

Zinc concentration of leaves of plants grown on SS amendment had a significant quadratic response to the main effect of fertilizer only at 41 days. At this time, for PM, the response for main effect of fertilizer was significantly linear. At 93 days, leaves from soil receiving the higher rate of SS had more Zn in leaf than at the lower rate. For SS at 41 and 63 days, the average Zn concentration in the leaf tissue was 58.8 and 53.8 $mg.kg^{-1}$, respectively. For PM, at the same date, the average Zn concentration was 32.3 and 33.5 $mg.kg^{-1}$. At both dates, significant difference between these two sources for Zn was observed (Tables A-24 and 40).

Copper concentrations in leaf tissue were affected significantly when SS was used. At the first and last leaf samplings, significant difference was found for Cu level from SS rates. Also at this same time, interaction in Cu values between SS rates and fertilizer level was significant. Average Cu concentration in leaf from SS was significantly higher than average Cu observed for PM at all leaf samplings (Tables A-24 and 40).

Effect of inorganic amendments on micronutrients and Cd concentration in tomato leaf tissue are shown in Table 41. Cadmium concentration was not affected significantly when FO or BC was used (Tables A-24 and 41). Manganese concentration in leaf had a significant quadratic response to fertilizer level at 41 days when FO was the amendment source. At 63 and 93 days, Mn was not affected significantly when FO was used. When BC was the amendment source, both the first and the last leaf sampling had statistical difference in leaf Mn between BC rates. Average Mn concentration for FO was quite similar to that observed for BC at all leaf samplings and no statistical difference was observed between them at the same leaf sampling date.

Iron concentration in leaf tissue was only affected significantly by BC treatment. At 41 and 93 days, significant difference in tissue Fe was observed between rates. Also, at these dates, significant main effect for fertilizer on Fe in leaf tissue was observed. With increase in the fertilizer level, Fe content in the leaf decreased linearly (Tables A-24 and 41). Average leaf Fe concentrations for FO was significantly higher than the average Fe observed for BC at 41 and 93 days after transplant (Tables A-24 and 41).

Zinc concentration in leaf had a significant linear positive response to fertilizer level when FO was used. For BC, at 63 and 93 days, significant difference between rates was observed. Also, for BC at 41 and 63 days, the main effect of fertilizer level had a significant linear positive response for Zn in leaf tissue. At the first two leaf samplings, the average Zn content in leaf for FO was significantly higher than that observed for BC (Tables A-24 and 41).

Table 41. Effects of inorganic amendment sources and rates and of fertilizer level on micronutrients and Cd concentrations of leaf at three dates of transplant. Tomato experiment, 1983.

	Fertilizer only			Bentonite clay					
				1.12 Mg.ha^{-1}			2.24 Mg.ha^{-1}		
	Fertilizer level								
Time	1400	2800	4200	1400	2800	4200	1400	2800	4200
Days					Cd, mg.kg^{-1}				
41	0.41	0.58	0.50	0.66	0.50	0.58	0.58	0.41	0.46
63	0.25	0.25	0.25	0.50	0.50	0.50	0.50	0.50	0.50
93	0.83	0.50	0.416	0.50	0.50	0.50	0.50	0.41	0.50
					Mn, mg.kg^{-1}				
41	55	89	83	76	75	77	70	56	70
63	188	181	176	146	160	177	170	180	153
93	312	295	300	316	286	270	336	333	333
					Fe, mg.kg^{-1}				
41	174	176	170	180	123	134	133	134	111
63	92	78	98	78	78	83	83	80	91
93	110	82	148	106	86	88	96	85	83
					Zn, mg.kg^{-1}				
41	34	36	44	22	28	30	42	25	28
63	30	44	44	26	29	34	36	28	37
93	30	38	44	25	25	31	35	38	43
					Cu, mg.kg^{-1}				
41	3.0	4.4	5.1	3.8	4.8	4.3	4.4	3.8	4.6
63	7.1	5.8	6.5	6.6	7.0	5.9	5.6	5.7	6.5
93	6.7	6.4	6.8	7.5	6.0	6.2	6.0	6.3	7.5

Copper concentration in leaf tissue, when inorganic amendments were used, had significant differences for FO. At 41 and 93 days, the effect of fertilizer had linear positive trends with fertilizer level for Cu content in tomato leaf. At all leaf samplings, the average Cu concentration for FO was not significant from that observed for BC (Tables A-24 and 41).

Between organic and inorganic amendments (Tables A-24, 40 and 41) both Cd and Cu were higher from organic sources at all leaf samplings. Concentration of Mn and Zn at the first two leaf samplings was significantly higher for organic amendments than that obtained for inorganic amendments. Between organic amendments, the elements mentioned above had a higher concentration when SS was the amendment source.

Analysis of variance for macro- and micronutrients and Cd concentration in tomato fruit are shown in Table A-25. No significant differences between treatments were observed for Ca, Zn and Fe, and consequently they were not reported in Table A-25.

Effects of organic and inorganic amendments on macronutrient concentration in tomato fruit are shown in Table 42. When fertilizer level was combined with SS, the main effect of fertilizer level had a significant linear positive response for N in tomato fruit. No statistical difference between SS rates was found for N in fruit. However, the higher PM rate tissue N concentration was significantly higher than that observed for PM at the lower rate. Average N in fruit observed with SS did not differ from average N level obtained with PM (Tables A-25 and 42). Nitrogen concentration in fruit, when FO was used, showed a significant linear positive response to fertilizer

Table 42. Effect of organic and inorganic amendment source and rate and of fertilizer level on macronutrient concentrations of tomato fruit at 91 days after transplant. Tomato experiment, 1983.

Fert. level	Fertilizer only	Sewage sludge ($Mg.ha^{-1}$)		Poultry manure ($Mg.ha^{-1}$)		Bentonite clay($Mg.ha^{-1}$)	
		11.2	22.4	11.2	22.4	1.12	2.24
$kg.ha^{-1}$							
	N, $g.kg^{-1}$						
0	-	22.7	24.5	24.7	26.5	-	-
1400	21.2	23.2	26.3	24.6	26.8	20.5	23.7
2800	21.9	24.5	26.7	24.2	26.4	22.0	21.3
4200	24.7	-	-	-	-	25.1	25.1
	P, $g.kg^{-1}$						
0	-	5.51	5.20	6.21	5.10	-	-
1400	4.41	5.21	6.71	5.91	5.82	5.21	5.61
2800	4.42	5.30	5.91	5.80	5.51	5.22	4.90
4200	3.73	-	-	-	-	5.42	5.60
	K, $g.kg^{-1}$						
0	-	22.91	31.61	32.01	35.81	-	-
1400	30.51	30.81	26.92	33.71	35.82	26.61	36.21
2800	30.62	37.81	29.71	32.90	42.50	32.40	33.30
4200	38.73	-	-	-	-	32.50	29.00
	Ca, $g.kg^{-1}$						
0	-	4.51	5.01	3.21	4.71	-	-
1400	4.01	4.70	5.02	4.42	4.20	3.71	3.61
2800	4.22	4.90	5.02	3.61	5.31	4.01	4.32
4200	4.33	-	-	-	-	3.72	4.82
	Mg, $g.kg^{-1}$						
0	-	1.61	1.82	1.62	1.62	-	-
1400	1.42	1.92	1.81	1.60	1.71	1.61	1.71
2800	1.63	1.91	1.84	1.62	1.91	1.82	1.62
4200	1.71	-	-	-	-	1.80	1.71

level. For BC amendment, main effect of fertilizer had a significant linear positive response. Average N concentration found with FO did not differ from the average N obtained with BC (Tables A-25 and 42).

Average N in fruit for organic amendment treatments was 25.1 $g.kg^{-1}$, which was significantly higher than the average observed for treatments with inorganic amendments, which was 22.8 $g.kg^{-1}$ (Tables A-25 and 42).

Phosphorus concentration in fruit was significant only for interaction between SS rate and fertilizer level. Average P concentration in fruit for PM was significantly higher than that which came from SS amendment.

For inorganic amendments, P in fruit was not affected significantly by BC or FO treatments. However, the average P content observed for BC was significantly higher than the average P observed for FO (Tables A-25 and 42). Average P values for organic amendments was significantly different from those observed for inorganic amendments.

Potassium concentration in fruit was affected significantly by SS and PM applications. For SS, main effect of fertilizer was a linear positive response for K content in fruit. But, the interaction between SS rate and fertilizer level also was significant. For PM, the higher rate of amendment gave significantly higher K than from the lower rate. Average K in fruit for SS was lower and was statistically different from the average K obtained for PM (Tables A-25 and 42). When inorganic sources were utilized, interaction between BC rate and fertilizer level was significant for K concentration. However, applications of FO did not significantly affect the fruit K concentration.

Average K concentration in fruit for organic amendments did not differ significantly from the average obtained for inorganic amendments (Tables A-25 and 42).

Magnesium content of tomato fruit was affected significantly when SS was used. At 22.4 $Mg.ha^{-1}$ of SS, the concentration of Mg was significantly higher than at 11.2 $Mg.ha^{-1}$. Main effect of fertilizer levels had a significant quadratic response for Mg from increase in fertilizer levels. Average Mg concentration of fruit from soil treated with SS was significantly higher than the average observed for PM. The average Mg in fruit from organic amendment sources was statistically higher than the average Mg found for inorganic amendments (Tables A-25 and 42).

Effects of organic and inorganic amendments on micronutrients and Cd concentrations of tomato fruit are shown in Table 43. Analysis of variance showed statistical significance among treatments for Mn, Cu and Cd (Table A-25).

For SS, the Mn concentration in fruit tissue had a response to give the main effect of fertilizer that was significantly linear positive response with increase in the fertilizer level. However, for PM, the Mn concentration was significantly affected by amendment rates, although the higher PM rate resulted in 22.8 $mg.kg^{-1}$ compared to 21.0 $mg.ha^{-1}$ at the lower rate. When average Mn concentration for SS was compared with average for PM, no statistical difference was obtained.

When inorganic amendments were used, the only significance observed for Mn concentration in fruit was for the interaction between BC rates and fertilizer levels (Tables A-25 and 43). Average Mn concentration observed for FO was not different from that observed for BC

Table 43. Effect of organic and inorganic amendment sources and rates and of fertilizer levels on mean micronutrient and Cd concentrations of tomato fruit at 91 days after transplant. Tomato experiment, 1983.

Fert. level	Fertilizer only	Sewage sludge ($Mg.ha^{-1}$)		Poultry manure ($Mg.ha^{-1}$)		Bentonite clay ($Mg.ha^{-1}$)	
		11.2	22.4	11.2	22.4	1.12	2.24
$kg.ha^{-1}$							
				Cd, $\mu g.kg^{-1}$			
0	-	13.49	21.02	6.56	6.56	-	-
1400	5.43	18.59	26.79	6.82	6.29	6.01	3.55
2800	5.10	31.56	42.08	6.56	7.08	2.63	2.93
4200	5.74	-	-	-	-	3.90	2.10
				Mn, $mg.kg^{-1}$			
0	22.4	21.3	20.1	20.0	-	-	
1400	21.5	24.3	23.1	21.0	22.8	20.5	21.4
2800	21.4	24.0	25.4	22.0	25.8	21.5	21.6
4200	23.5	-	-	-	-	24.0	21.3
				Fe, $mg.kg^{-1}$			
0	-	54.1	52.5	41.6	51.6	-	-
1400	43.3	54.1	52.5	55.0	51.6	44.1	45.0
2800	47.5	51.6	46.5	44.8	45.0	45.1	47.5
4200	40.8	-	-	-	-	47.3	46.0
				Zn, $mg.kg^{-1}$			
0	-	44.6	30.6	26.0	28.0	-	-
1400	36.3	37.6	39.6	27.0	32.3	29.3	27.3
2800	28.0	33.0	54.0	33.3	51.3	32.0	28.6
4200	40.6	-	-	-	-	47.3	27.3
				Cu, $mg.kg^{-1}$			
0	-	8.1	8.1	6.1	7.2	-	-
1400	6.1	8.0	9.2	6.2	7.3	6.1	7.1
2800	7.1	9.1	10.0	8.1	8.1	5.2	6.2
4200	7.3	-	-	-	-	6.1	6.2

treatments. The average Mn in tomato fruit when organic amendments were used was significantly higher from that observed for inorganic amendments (Tables A-25 and 43).

For Cu concentration in fruit, the influence of the two PM rates was significantly different from each other. At 11.2 and 22.4 $Mg.ha^{-1}$, Cu concentration was 6.8 and 7.5 $mg.kg^{-1}$, respectively. Sewage sludge application did not affect the Cu concentration in fruit. Average means between both PM rates was significantly higher than that obtained for SS (Tables A-25 and 43). Inorganic amendments did not affect the Cu concentration in fruit (Tables A-25 and 43). Mean Cu level observed among organic amendments was significantly different from the Cu level obtained for inorganic amendments.

Cadmium concentration in fruit was affected significantly only when SS was used (Table A-25). For SS at 22.4 $Mg.ha^{-1}$, the level of Cd in fruit was 30 $\mu g.kg^{-1}$ and statistically differed for 21 $\mu g.kg^{-1}$ obtained from SS at 11.2 $Mg.ha^{-1}$ (Table 43). Cadmium concentration in fruit had a linear positive response for main effect of fertilizer levels (Tables A-25 and 43). Highest Cd concentrations were observed when SS was used and these Cd values were significantly different than those for fruit from PM amendments (Tables A-25 and 43). Organic amendments had an average Cd concentration in fruit of 16 $\mu g.kg^{-1}$ which was significantly different from that observed for inorganic amendments which was 4.15 $\mu g.kg^{-1}$ (Tables A-25 and 43).

As stated previously, SS, PM, BC, and FO were compared for macronutrient concentrations in fruit for seven treatments selected from the original 21 treatments. The analysis of variance and main effect of amendment sources and fertilizer level are shown in Table 44.

Macronutrient concentrations in fruit, except for Ca, were affected significantly by amendment source, however, fertilizer levels had no effect (Table 44).

Nitrogen concentration in fruit from PM at 22.4 $Mg.ha^{-1}$ and SS at both rates did not differ from each other. However, they did differ in N content from FO and BC at both rates. Fruit from the latter sources were not different in N content (Table 44).

Phosphorus concentration was significantly higher for SS at 22.4 $Mg.ha^{-1}$ than that for FO. The lowest P concentration was observed for FO and was significantly different from the other six treatments (Table 44).

Potassium concentrations of fruit from SS and PM at 11.2 $Mg.ha^{-1}$, PM at 22.4 $Mg.ha^{-1}$ and BC at 2.24 $Mg.ha^{-1}$ were not statistically different. However, PM at the higher rate had the highest K concentration which was statistically different from that for SS at 22.4 $Mg.ha^{-1}$, BC at 1.12 $Mg.ha^{-1}$ and FO (Table 44).

Magnesium concentration in fruit from SS at 11.2 $Mg.ha^{-1}$ and PM at 22.4 $Mg.ha^{-1}$ had the highest concentrations which were statistically different from the other five treatments. The lowest Mg concentration was found for FO, PM at 11.2 $Mg.ha^{-1}$ and BC at 1.12 $Mg.ha^{-1}$ (Table 44).

Cucumber Experiment. Fall, 1983

Cucumber Fruit Yield

Residual effects of amendment source, amendment rate and fertilizer level applied to tomato in the Spring, 1983, were evaluated by seeding cucumber through the plastic mulch, leaving the soil undisturbed. The plots were split with one-half receiving additional N and K in liquid form as described previously.

Table 44. Analysis of variance and main effect of amendments and fertilizer on macronutrient concentrations of fruit at 91 days after transplant. Tomato experiment, 1983.

Source of variation	df	N	P	K	Ca	Mg
		----------	----------	Mean square	----------	----------
Blocks	2	28.94	0.126	3.305	0.078	0.063
Amendment (A)	6	33.56***	2.195***	82.816*	1.333*	0.107***
Fertlizer level (F)	1	0.03	0.656	74.400	0.663	0.013
AxF	6	2.27	0.161	23.451	0.478	0.023
Error	26	2.66	0.389	33.561	0.523	0.018
Amendment$^+$		----------	----------	g.kg^{-1}	----------	----------
SS (11.2 Mg.ha^{-1})		26.3ab^y	5.2b	34.3ab	4.8ab	1.6a
SS (22.4 Mg.ha^{-1})		26.5a	6.3a	28.3b	5.0a	1.7bc
PM (11.2 Mg.ha^{-1})		24.4bc	5.8ab	33.3ab	4.0b	1.6cd
PM (22.4 Mg.ha^{-1})		26.6a	5.6ab	39.1a	4.8ab	1.8ab
BC (1.12 Mg.ha^{-1})		21.3d	5.2b	29.5b	3.9b	1.7bc
BC (2.24 Mg.ha^{-1})		22.5cd	5.3b	34.7ab	4.2ab	1.6cd
FO		21.5d	4.4c	30.5b	3.8b	1.5d
F value		***	***	*	*	***
Fertilizer level (kg.ha^{1})						
1400		2.4	5.5	31.4	4.2	1.7
2800		2.4	5.3	34.1	4.5	1.7
F value		NS	NS	NS	NS	NS

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

^{y}Treatment mean separation within columns by Duncan's Multiple Range Test, 5% level.

$^+$See Table 20 for abbreviations.

Analyses of variance are shown in Table A-26. These included early and final average fruit weight, as well as early and final fruit yield. Replicate effect and main effect of treatment were statistically significant. With additional N and K, main effect for early and final fruit yield had significance. Interaction between treatment and NK application was not statistically significant. Consequently, the contrast shown in Table A-26 takes into consideration the main effect of treatments. These means for the main effect of treatments and of NK application are shown in Table 45.

Average fruit weight at early season (first three harvests) was higher than final weight for all treatments (Table 45).

Residual effect of organic amendment for SS had statistical difference between rate and for PM there was a significant quadratic main effect of fertilizer level on average early fruit weight. For SS, the early average fruit weight was 279.3 g which was statistically different from 311.2 g obtained for PM (Tables A-26 and 45).

For inorganic amendments, FO did not have any significant effect. However, interaction between BC and fertilizer level was significant for early average fruit yield (Tables A-26 and 45).

Comparisons between organic and inorganic amendments indicated that a significantly higher average early fruit weight (316 g) for inorganic compared to the average for organic amendments (295 g). Final average fruit weight for organic and inorganic amendments did not have any significant contrast. However, fruit from the PM amendment has significantly higher final average fruit weight than for SS or inorganic amendments (Tables A-26 and 45).

Table 45. Main residual effect of 21 treatments and of NK application on early and final average of fruit weight and yield. Cucumber experiment, 1983.

Amendment		Fertilizer level	Average fruit weight (g)		Fruit yield	
Source[+]	Rate		Early	Final	Early	Final
	Mg.ha^{-1}	kg.ha^{-1}	g		Mg.ha^{-1}	
	Treatment			Inorganic amendment		
FO		1400	308.9	266.1	12.2	24.1
		2800	307.1	260.4	14.2	24.2
		4200	333.0	273.4	16.5	28.8
BC	1.12	1400	307.5	259.6	15.7	25.8
	1.12	2800	330.1	272.5	17.0	28.0
	1.12	4200	328.9	264.2	17.6	29.7
BC	2.24	1400	316.8	274.4	17.5	31.4
	2.24	2800	315.2	268.2	21.3	35.1
	2.24	4200	292.9	261.5	16.2	29.3
				Organic amendment		
SS	11.2	0	279.3	244.3	11.9	21.8
	11.2	1400	283.8	255.1	17.9	31.5
	11.2	2800	297.8	258.2	17.0	28.0
SS	22.4	0	279.2	234.5	13.0	26.4
	22.4	1400	261.1	234.5	20.5	34.6
	22.4	2800	275.1	253.5	19.8	34.9
PM	11.2	0	305.1	267.7	14.5	28.3
	11.2	1400	326.8	267.8	17.4	29.2
	11.2	2800	301.3	263.0	23.3	36.4
PM	22.4	0	306.9	269.9	22.4	35.1
	22.4	1400	324.6	281.8	20.8	40.0
	22.4	2800	302.5	272.9	21.6	41.7
	NK application					
	-NK		303.3	261.2	16.8	29.7
	+NK		304.7	263.9	18.2	31.7

[+] See Table 20 for abbreviations.

Application of additional NK did not have a significant effect on early or final average fruit weight (Tables A-26 and 45).

Cucumber fruit yield was affected both by residual treatment and NK application (Table A-26). For early fruit yield, FO amendment had a linear positive response for residual fertilizer from the 1400 to 4200 $kg.ha^{-1}$, applied for tomato. For BC, the early fruit yield had a significantly quadratic response for main effect of residual fertilizer. Average early fruit yield for FO was 14.3 $Mg.ha^{-1}$ and for BC was 17.5 $Mg.ha^{-1}$. These two means were statistically different from each other (Tables A-26 and 45).

For organic amendment, the two rates for SS and PM were statistically different. For SS, the main effect of fertilizer level was a significant quadratic response. For PM, the main effect of fertilizer showed a significant linear and positive trend. Since the interaction between PM rates and fertilizer level was significant, interaction effect should be considered (Tables A-26 and 45). Average early fruit yield for PM was 20 $Mg.ha^{-1}$ which was significantly higher than 16.7 $Mg.ha^{-1}$ for SS.

When organic and inorganic amendments were compared, the average early fruit yield obtained between treatments was significantly different. Organic and inorganic amendment average early fruit yields were 18.3 and 15.9 $Mg.ha^{-1}$, respectively (Tables A-26 and 45).

Final cucumber fruit yield ranged from 24.1 to 35.1 $Mg.ha^{-1}$ for inorganic amendments and ranged from 21.8 to 41.7 $Mg.ha^{-1}$ for organic amendments. For inorganic amendment, as observed at the early season for FO, the response of final fruit yield to higher residual fertilizer level was linear and positive. For the higher rate of BC, the final fruit yield was significantly higher than at the lower rate. The main effect for residual fertilizer soil receiving BC was a significant quadratic response to fertilizer level. However, interaction between BC rate and fertilizer level was significant for final fruit yield (Tables A-26 and 45). Average final fruit yield for F0 was 25.7 $Mg.ha^{-1}$ and this was significantly lower than 29.9 $Mg.ha^{-1}$ observed for BC (Tables A-26 and 45).

For both organic amendments at 22.4 $Mg.ha^{-1}$, the final fruit yield was significantly higher than at the lower rate. For SS, the main effect of fertilizer was a significant quadratic response. However, for PM, the main effect of fertilizer was linear and positive (Tables A-26 and 45). Average final fruit yield for PM was 35.1 $Mg.ha^{-1}$ and this was significantly higher than 29.5 $Mg.ha^{-1}$ observed for SS (Tables A-26 and 45).

Organic and inorganic amendments differed statistically from each other in regard to average final fruit yield. For organic amendment, the average final fruit yield was 32.3 $Mg.ha^{-1}$ compared to 28.5 $Mg.ha^{-1}$ for inorganic amendment (Tables A-26 and 45).

Application of NK significantly increased the early and final fruit yield by 1.4 and 2.0 $Mg.ha^{-1}$, respectively, in relation to early and final yield observed without application of NK (Tables A-26 and 45).

In order to compare BC, SS and PM amendments with and without NK application, the seven treatments receiving 1400 and 2800 $kg.ha^{-1}$ of fertilizer for tomato were selected. Analysis of variance and main effect of treatments with and without NK application are shown in Table 46. Average fruit weight, both early and final, were not affected significantly by treatment, fertilizer level or application of NK fertilizer. However, early and final fruit yields were affected significantly by treatment and NK application (Table 46). The early fruit yield from FO and BC amendment at 1.12 $Mg.ha^{-1}$ or SS at 11.2 $Mg.ha^{-1}$ did not differ from each other. However, yield from FO differed from the other four treatments. The highest early fruit yield of 21.2 $Mg.ha^{-1}$ was obtained with PM at 22.4 $Mg.ha^{-1}$ and the lowest yield was 13.2 $Mg.ha^{-1}$ obtained for FO.

For final fruit yield, highest yields were 40.8 and 34.7 $Mg.ha^{-1}$ for PM and SS at 22.4 $Mg.ha^{-1}$, respectively. These two treatments did not differ from each other. However, fruit yield for PM at 22.4 $Mg.ha^{-1}$ was significantly more than from the other five treatments. The lowest final fruit yield was observed for FO, which was 24.1 $Mg.ha^{-1}$ (Table 46).

Application of NK significantly increased the early and final fruit yields by 1.1 and 2.6 $Mg.ha^{-1}$, respectively, relative to early and final fruit yield obtained with no application of NK (Table 46).

Soil Analysis

Nitrogen Availability

Statistical analysis for extracted soil N indicated that there was a significant effect of residual treatments on all N forms extracted (Table A-27). Means for these treatments are shown in Table 47.

For inorganic amendments, NO_3^--N concentration showed a significant, linear, positive response to increase in original fertilizer level from 1400 to 4200 $kg.ha^{-1}$ when FO was utilized. The main effect of fertilizer for BC treatment was significantly linear and positive (Tables A-27 and 47). The average NO_3^--N for FO was 24.3 $mg.kg^{-1}$ and this differed statistically from 17.6 $mg.kg^{-1}$ obtained for BC.

Table 46. Analysis of variance and main effect of amendment treatment, fertilizer level and NK application on average fruit weight and fruit yield of cucumber. Cucumber experiment, 1983.

Source of variation	df	Average fruit weight		Fruit yield	
		Early	Final	Early	Final
		Mean square			
Block	2	2577.5	2178.3	25.3	94.6**
Treatment (T)	6	4053.3	1354.6	95.5**	361.0***
Fertilizer level (F)	1	0.0	37.1	63.6	58.8
T x F	6	1033.9	346.7	17.3	33.4
Erro (a)	26	2117.7	996.5	28.8	61.0
NK	1	0.1	0.6	26.1*	77.7**
NK x T	6	1245.7	343.9	3.7	5.7
NK x L	1	0.6	188.9	1.3	1.7
NK x T x L	6	639.0	549.6	6.9	5.0
Erro (b)	28	438.1	217.7	6.0	10.2
Treatment[+]					
SS (11.2 Mg.ha^{-1})		291	256	17.4 ab	29.7 bcd
SS (22.4 Mg.ha^{-1})		268	244	20.2 a	34.7 ab
PM (11.2 Mg.ha^{-1})		314	265	20.3 a	32.8 bc
PM (22.4 Mg.ha^{-1})		313	277	21.2 a	40.8 a
BC (1.12 Mg.ha^{-1})		318	266	16.4 ab	26.9 cd
BC (2.24 Mg.ha^{-1})		316	271	19.3 a	33.3 bc
FO		308	263	13.2 b	24.1 d
F value		NS	NS	**	***
Fertilizer level (kg.ha^{-1})					
1400		304.1	262.8	17.4	30.9
2800		304.2	264.2	19.1	32.6
F value		NS	NS	NS	NS
NK application					
-NK		304.1	263.6	17.7	30.2
+NK		304.2	263.4	18.8	32.8
F value		NS	NS	*	**

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[+] See Table 20 for abbreviations.

Table 47. Effect of residual 21 treatments on mean soil N extracted, pH, EC and moisture at 3 days after cucumber seeding. Cucumber experiment, 1983.

Treatments									
Amendment		Fert.	Water extract		KCl extract	Mehlich I			
Source[+]	Rate	level	NO_3^--N	NH_4^+-N	NH_4^+-N	NH_4^+-N	pH	EC	Moisture
	$Mg.ha^{-1}$	$kg.ha^{-1}$	mg.kg^{-1}					dS.m^{-1}	
						Inorganic amendment			
FO		1400	15	0.6	1.4	1.8	6.39	0.36	170
		2800	21	0.2	1.2	1.2	6.30	0.42	147
		4200	37	0.5	1.5	1.4	6.33	0.88	158
BC	1.12	1400	11	0.3	0.7	0.9	6.22	0.34	145
	1.12	2800	15	0.4	1.6	0.9	6.34	0.42	161
	1.12	4200	29	0.6	1.2	1.7	5.96	0.33	154
BC	2.24	1400	15	0.5	1.6	1.7	6.09	0.39	167
	2.24	2800	17	0.2	1.8	1.6	6.24	0.37	169
	2.24	4200	19	0.4	0.6	0.9	6.14	0.53	165
						Organic amendment			
SS	11.2	0	17	0.5	1.7	1.6	6.27	0.59	145
	11.2	1400	23	0.3	1.2	1.4	6.33	0.62	148
	11.2	2800	36	0.4	1.4	1.8	6.34	0.85	146
SS	22.4	0	66	0.7	1.6	0.9	6.26	0.59	175
	22.4	1400	58	0.3	1.0	1.3	6.18	0.70	151
	22.4	2800	109	0.4	0.9	0.9	5.97	0.88	152
PM	11.2	0	41	0.4	0.9	0.8	6.21	0.25	151
	11.2	1400	44	0.3	1.2	0.7	6.36	0.36	143
	11.2	2800	53	0.2	0.6	0.5	6.30	0.80	159
PM	22.4	0	32	0.7	1.3	0.8	6.40	0.71	161
	22.4	1400	54	0.2	1.3	1.3	6.57	0.95	152
	22.4	2800	104	0.3	1.2	1.8	5.95	0.97	149

[+] See Table 20 for abbreviations.

For organic amendments, both rates of SS and PM had a significant effect between these sources for NO_3^--N. Linear and quadratic main effect of fertilizer level also were significant for both organic sources. However, interaction between rates of SS and PM with fertilizer level was statistically significant. Average NO_3^--N concentration for SS did not differ from that observed for PM (Tables A-27 and 47). Average NO_3^--N concentration for organic and inorganic amendments was 53.0 and 20.0 $mg.kg^{-1}$, respectively, and these were statistically different from each other (Tables A-27 and 47).

Ammonium-N concentration in water for inorganic amendments had significant quadratic response with increase in residual fertilizer level when FO was used. For BC, the main effect of fertilizer also had a significant quadratic response (Tables A-27 and 47). For organic amendments, NH_4^+-N concentration in water, a main effect of fertilizer was a quadratic response for both SS and PM. However, for PM the interaction between amendment rate and fertilizer level was significant (Tables A-27 and 47).

Exchangeable NH_4^+-N concentrations determined by 1 M KCl or by Mehlich I extract gave similar values. Therefore, only data obtained with 1 M KCl will be reported. With the inorganic amendments, exchangeable NH_4^+-N was not affected significantly when FO was utilized. For BC, the main effect of fertilizer was a significant quadratic response, but the interaction between BC rate and fertilizer level was significant for exchangeable NH_4^+-N (Tables A-27 and 47).

When SS amendment was utilized, the main effect of fertilizer level was a linear negative response for exchangeable NH_4^+-N. For PM at the higher rate, the level of exchangeable NH_4^+-N was significantly higher than for PM at the lower rate (Tables A-27 and 47). As observed for NH_4^+-N in water, when averages of exchangeable NH_4^+-N were compared between organic and inorganic amendment, no statistical significance was observed (Tables A-27 and 47).

Available total N or TN, as NO_3^--N in water plus NH_4^+-N in 1 M KCl, was found to be much lower from soil with an inorganic amendment than that for organic amendment (Fig. 10). For organic amendment, available TN ranged from 18.7 to 109.9 $mg.kg^{-1}$ for SS, compared to 33.3 to 105.2 $mg.kg^{-1}$ for PM. For both organic amendments at 22.4 $Mg.ha^{-1}$, significantly higher available TN was observed than at 11.2 $Mg.ha^{-1}$. For both SS and PM treatments, the main effect of fertilizer was a significant quadratic response for available TN. Although, for both amendment sources, the interaction between rate and fertilizer level was significant and therefore should be considered instead of the main effect (Table A-27 and Fig. 10). Residual available total N for SS and PM were 52.8 and 55.7 $mg.kg^{-1}$, respectively, and were not statistically different.

When FO was used, a significant linear positive increase in residual total available N was observed. Likewise, for BC, the main effect of fertilizer level was a significant linear positive increase in TN and the average available TN between the two sources was statistically different (Table A-27). For FO, the average available TN was 25.9 $mg.kg^{-1}$ and for BC it was 18.9 $mg.kg^{-1}$ (Fig. 10).

Average available TN for organic amendment was 54.2 $mg.kg^{-1}$ and this was significantly higher than the corresponding average observed for inorganic amendments, which was 22.4 $mg.kg^{-1}$ (Table A-27).

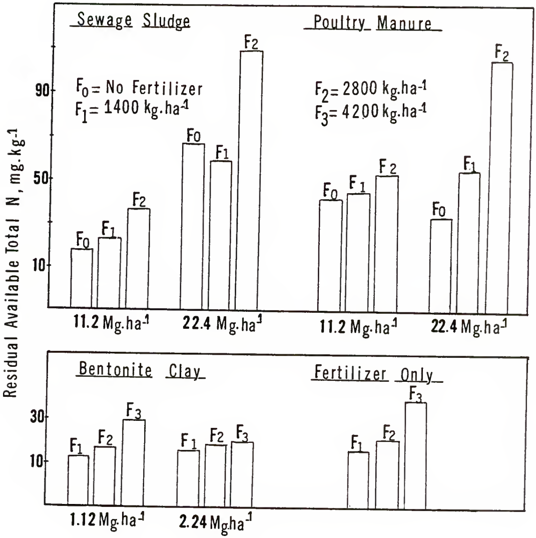

Fig. 10 Residual available total nitrogen in soil for 21 treatments at three days after cucumber seeding. Cucumber experiment, 1983.

Soil Reaction, Electrical Conductivity and Moisture

Analysis of variance for soil pH, EC and moisture indicated significance only among treatments for EC (Table A-27). Means for soil pH, EC and moisture are shown in Table 47. Values for soil pH and moisture ranged from 5.95 to 6.75 and 143 to 175 $g.kg^{-1}$, respectively.

Values observed for EC were lower in all treatments than those observed at the last tomato soil sampling (Table 47). For inorganic sources, EC had a significant linear positive response to original increase in the fertilizer level. For this amendment, EC ranged from 0.36 to 0.88 $dS.m^{-1}$ for original fertilizer applied at 1400 and 4200 $kg.ha^{-1}$, respectively. Average EC for F0 was 0.55 $dS.m^{-1}$ and was significantly higher than 0.39 $dS.m^{-1}$ observed for BC treatments (Tables A-27 and 47). For organic amendment, both SS and PM at 22.4 $Mg.ha^{-1}$ had EC values which were significantly higher from those observed at 11.2 $Mg.ha^{-1}$. For PM, the main residual effect of fertilizer level was a significant linear main effect (Tables A-27 and 47). Average of EC observed for organic amendment, 0.69 $dS.m^{-1}$, was significantly higher than that observed for inorganic amendments which was 0.47 $dS.m^{-1}$ (Tables A-27 and 47).

Ion Concentration in Water and Mehlich I Extracts

Means for Ca, Mg, and Cl in water extracts and for Ca, Mg, and P in Mehlich I extracts are shown in Table A-28. Water extractable, Ca concentration ranged from 27 to 135 $mg.kg^{-1}$, Mg from 10 to 41 $mg.kg^{-1}$ and Cl from 13 to 60 $mg.kg^{-1}$ (Table A-28).

In Mehlich I extract, Ca concentration ranged from 1300 to 2240 $mg.kg^{-1}$, Mg from 137 to 380 $mg.kg^{-1}$, and P from 173 to 335 $mg.kg^{-1}$ (Table A-28).

Analysis of variance and means of 21 residual treatments for soluble and exchangeable K are shown in Table A-27 and Fig. 11. For inorganic amendments, soluble K concentration found when FO was used had a significant linear positive effect to increase of fertilizer level. No such significant difference was observed for BC. However, the average soluble K found for BC was 15.6 $mg.kg^{-1}$ which was significantly higher than 6.6 $mg.kg^{-1}$ observed for FO (Table A-27 and Fig. 11).

For organic amendments, soluble K concentration for PM at the higher rate was significantly higher than for PM at the lower rate. Main effect of fertilizer for PM and interaction effect between PM rate and fertilizer level were significant. However, application of SS did not affect significantly the soil soluble K concentration. The average soluble residual K values found for PM and SS were 38.5 and 28.5 $mg.kg^{-1}$, respectively, and these means differed statistically from each other (Table A-27 and Fig. 11).

Exchangeable K concentration for FO had a significant quadratic response to increase in the level of tomato fertilizer applied. For BC at 2.24 $Mg.ha^{-1}$, the exchangeable K concentration was significantly higher than that for BC at 1.12 $Mg.ha^{-1}$. Interaction between BC rate and fertilizer level was significant (Table A-27). Average exchangeable K concentration for FO and BC were 110 and 69 $mg.kg^{-1}$, respectively, and these were significantly different (Table A-27 and Fig. 11).

For organic amendments, residual exchangeable K was not affected significantly by SS application. However, utilization of PM at the higher rate had significantly more residual exchangeable K than PM at the lower rate. Interaction between PM rate and fertilizer level was significant. Average exchangeable K for PM and SS was statistically

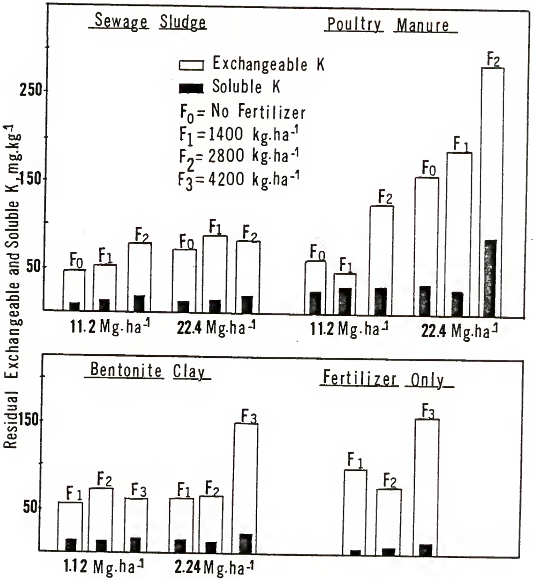

Fig. 11 Residual exchangeable and soluble K in soil for 21 treatments at three days after cucumber seeding. Cucumber experiment, 1983.

significant and these were 143.0 and 69.8 mg.kg^{-1}, respectively (Table A-27 and Fig. 11).

As observed for soluble K, the average exchangeable K concentration for organic amendments was 106.5 mg.kg^{-1} which was significantly higher than that of 89.3 mg.kg^{-1} observed for inorganic amendments (Table A-27 and Fig. 11).

Tissue Analysis

Nutrient Concentration in Leaf and Fruit

Means for the main effect of residual 21 treatments on leaf macro- and micronutrient concentrations are shown in Tables A-29 and 30.

In Table A-31, the analysis of variance for N and K concentration in cucumber leaf are shown at two dates after seeding. Concentration of these two nutrients at both leaf samplings were affected significantly by treatments and additional NK application. Means for main effects on leaf N and K concentration at two dates after seeding are shown in Table 48.

When FO amendments were utilized, residual effect of fertilizer level was not significant at both leaf samplings. The N concentrations for this amendment ranged from 36.1 to 40.6 g.kg^{-1} at 22 days and from 28.4 to 29.6 g.kg^{-1} at 47 days. For BC at 22 days, significant difference between amendment rates was observed. However, at 47 days, the main effect of fertilizer was a significant linear positive response (Tables A-31 and 48). At both leaf samplings, the average N concentrations found for BC and FO were not statistically different. Average N concentrations for FO and BC were 39.4 and 40.2 g.kg^{-1} at 22 days and 28.5 and 30.0 g.kg^{-1} at 47 days, respectively (Table 48).

Table 48. Main residual effect of treatment and of NK application on leaf N and K concentration at two dates after cucumber seeding. Cucumber experiment, 1983.

Amendment		Fert.	Leaf			
Source	Rate	level	N	K	N	K
	Mg.ha^{-1}	kg.ha^{-1}	g.kg^{-1}			
			22 days[^]		47 days[^]	
Treatment[+]				Inorganic amendment		
FO		1400	36.1	30.4	28.4	23.3
		2800	41.7	31.0	27.7	22.5
		4200	40.6	35.9	29.6	29.5
BC	1.12	1400	39.0	31.7	28.5	24.0
	1.12	2800	41.5	34.2	29.9	22.5
	1.12	4200	39.5	34.7	30.4	23.7
BC	2.24	1400	39.2	33.9	28.6	28.2
	2.24	2800	39.9	34.0	30.3	30.3
	2.24	4200	42.3	38.1	32.6	35.9
				Organic amendment		
SS	11.2	0	38.1	29.6	30.5	16.9
	11.2	1400	40.4	31.5	32.2	22.2
	11.2	2800	38.9	33.3	33.4	16.9
SS	22.4	0	36.7	29.5	36.5	16.6
	22.4	1400	34.1	29.4	33.3	16.2
	22.4	2800	35.4	33.2	35.1	17.8
PM	11.2	0	39.7	31.1	37.0	19.6
	11.2	1400	36.7	30.1	34.4	29.7
	11.2	2800	41.1	36.2	34.8	27.0
PM	22.4	0	41.3	33.8	37.0	31.2
	22.4	1400	40.6	39.2	39.0	35.7
	22.4	2800	43.9	38.5	41.9	42.3
F value			*	***	***	***
NK application						
-NK			37.8	31.4	32.9	22.3
+NK			40.9	35.3	33.0	26.0
F value			*	***	NS	**

[^] Days after seeding.

[+] See Table 20 for abbreviations.

For organic amendments, leaf N concentration from SS treatments had a similar pattern of statistical significance at both leaf samplings; higher amendment rate had significantly higher leaf N than at the lower rate but the interaction between SS rate and fertilizer level was significant (Table A-31 and 48). For PM at 22 days, the main effect of fertilizer on leaf N was significantly linear and positive with increase in the fertilizer level. At 47 days, leaf N concentration was significantly different between PM rates. However, at both leaf samplings, the interaction betweem PM rate and fertilizer level was statistically significant (Tables A-31 and 48). Average N concentrations in cucumber leaf for PM and SS were 40.5 and 37.2 $g.kg^{-1}$ at 22 days compared to 37.4 and 33.5 $g.kg^{-1}$ at 47 days, respectively. At both leaf samplings, these average N concentrations were statistically different between sources.

Organic amendments were compared with inorganic amendments in regard to the average N in leaf. At 22 days, they did not differ, however, at 47 days, type of amendment had an effect and differed from each other (Tables A-31 and 48). Average N concentrations at 22 days were 38.8 and 39.8 $g.kg^{-1}$ for organic and inorganic amendments, respectively. At 47 days, corresponding leaf N values were 35.4 and 29.2 $g.kg^{-1}$, respectively.

Potassium concentration in cucumber leaf at 22 days after seeding had a significant linear and positive response to FO levels. For BC treatment, at both leaf samplings, K concentration was significantly higher at the higher BC rate. However, average N concentration for FO and BC treatments was not statistically different at both dates (Tables A-31 and 48).

For organic amendments, statistical significance was observed for each amendment at each leaf sampling and was quite different in regard to K concentration of leaf (Table A-31). For SS at 22 days, a significant linear positive response for main effect of fertilizer on leaf K was observed. In addition, at 47 days, there was a significant difference in K content of leaf between SS rates. Quadratic response in leaf K was found for main effect of fertilizer. Interaction between SS rate and fertilizer level was observed (Tables A-31 and 48). For PM at 22 days, the higher rate had significantly higher mean K value than at the lower rate. The main effect of fertilizer level was a significant linear response for K concentration in the leaf. However, at this sampling date, the interaction between PM rate and fertilizer level needs to be considered because it was statistically significant (Tables A-31 and 48). At both leaf samplings, the average K concentrations found for PM treatments were statistically different from that observed for SS. The average K concentration for PM was 34.8 and 30.9 $g.kg^{-1}$ at 22 and 47 days, respectively. These averages for SS treatment were 31.0 and 17.7 $g.kg^{-1}$ at the same dates, respectively.

Average K concentration of cucumber leaf from organic amendments was only significantly different from that observed for inorganic amendment at 47 days. This occurred at 3 days previous to the first harvest. At this time, average K concentration was 24.3 and 26.2 $g.kg^{-1}$ for organic and inorganic amendments, respectively.

Additional application of NK increased significantly the N concentration in leaf at 22 days and K concentration at both leaf samplings. It was observed that increases in K concentration in cucumber leaf were much higher than those observed for N (Tables A-31 and 48).

Means for macro- and micronutrient content of cucumber fruit expressed as the main effect of 21 treatments were considered and are shown in Table A-32.

Analysis of variance for N and K concentration in cucumber fruit is shown in Table A-23. These statistical analysis indicated that both the main effects of treatment and of NK application were significant. However, the interaction between these two factors was also significant and should be considered instead of the main effect. Significant contrast mean square shown in Table A-33 takes into consideration this significant interaction.

Without NK application, BC at the higher rate had higher significant N value than at the lower rate. However, with application of NK, the main effect of tomato fertilizer level was a linear response for N concentration. Average N concentration for both BC and FO treatment, with or without application NK, was significantly different from each other (Tables A-33 and 49).

Without NK application, SS at the higher rate had significantly higher fruit N concentration than at the lower rate. In addition, the main effect of fertilizer level was a significant linear positive response for N concentration in fruit (Tables A-33 and 49). With additional application of NK, the two SS rates utilized were significantly different from each other in regard N concentration in fruit. Interaction between SS rate and fertilizer level was significant when additional NK was applied (Tables A-33 and 49). Average N in fruit

Table 49. Interaction effect between treatment and NK application on N and K concentration in cucumber fruit. Cucumber experiment, 1983.

Amendment		Fert.	Fruit			
Source	Rate	level	N		K	
	Mg.ha^{-1}	kg.ha^{-1}	g.kg^{-1}			
			-NK	+NK	-NK	+NK
Treatment[+]				Inorganic amendment		
		1400	17.7	18.4	28.8	33.4
FO		2800	17.2	16.5	32.1	28.1
		4200	17.3	17.0	38.0	30.9
	1.12	1400	21.8	16.7	32.8	37.2
BC	1.12	2800	17.6	18.7	26.7	29.9
	1.12	4200	17.7	18.8	34.2	32.1
	2.24	1400	21.5	20.3	38.9	49.1
BC	2.24	2800	19.4	19.2	38.0	36.1
	2.24	4200	20.4	20.8	34.0	40.7
				Organic amendment		
	11.2	0	17.7	20.5	28.4	39.1
SS	11.2	1400	23.8	22.2	26.5	29.9
	11.2	2800	22.6	23.2	31.4	27.3
	22.4	0	37.0	32.2	29.7	30.3
SS	22.4	1400	37.1	36.5	33.0	26.3
	22.4	2800	34.1	37.4	34.2	24.6
	11.2	0	21.2	21.6	34.3	27.5
PM	11.2	1400	20.9	23.0	32.3	29.4
	11.2	2800	20.1	22.2	38.4	28.4
	22.4	0	20.7	21.3	34.9	35.5
PM	22.4	1400	19.7	26.3	36.3	35.8
	22.4	2800	18.4	22.3	36.9	43.7

[+] See Table 20 for abbreviations.

for SS was statistically higher than the average observed for PM, with or without application of NK.

Average N concentration in fruit for organic and inorganic amendments was 24.4 and 18.9 $g.kg^{-1}$, with NK application, respectively, and 25.7 and 18.4 $g.kg^{-1}$ without NK application, respectively. These average N concentrations, with or without NK application were statistically different from each other.

Statistical significances for treatments with or without NK application were also different in regard to K concentration in cucumber fruit (Table A-33).

For inorganic amendment, without application of NK, a significant linear positive response to tomato fertilizer level was observed for K concentration in fruit. For BC at 2.24 $Mg.ha^{-1}$, the K concentration was significantly higher than that observed at 11.2 $Mg.ha^{-1}$ (Tables A-32 and 49). For inorganic amendment with application of NK, the interaction between BC rates and fertilizer level was significant for K concentration in fruit (Tables A-33 and 49). Average fruit K concentration observed for FO and BC was statistically different only when application of NK had been applied.

For organic amendment with NK application, SS and PM at 22.4 $Mg.ha^{-1}$ had significantly higher K in fruit than at 11.2 $Mg.ha^{-1}$. For SS, the main effect of fertilizer had a significantly linear positive response for K with increased level of tomato fertlizer (Tables A-33 and 49). Average K concentrations in fruit were 35.5 and 30.5 $g.kg^{-1}$ for PM and SS without NK application, respectively, and were 33.3 and 29.5 $g.kg^{-1}$ with NK application, respectively. These K averages observed with or without NK application were statistically different from each other when the same amendment source were compared.

DISCUSSION

Tomato and Cucumber Yields

In both years, tomato fruit yield in size category 1 was not affected by treatments. However, fruit in sizes 2 and 3 and total yield yields were highest for soil amended with PM or SS. Lowest yields were with FO for all fruit size categories and total yield. Other researchers (Giordano et al., 1975; Stucky and Newman, 1977) have reported adequate crop yields in the field using organic wastes as agricultural soil amendments. In general, their findings indicated that the yield response to organic waste is quadratic, declining at excessive high rates due to factors such as inhibition of germination, phytotoxicity of heavy metals and immobilization of available N due to a high C:N ratio. This quadratic effect was not evaluated in this study because only one rate in 1982 and two rates of organic amendment in 1983 were utilized. However, the 1983 tomato yields increased with increase in SS rate from 11.2 to 22.4 $Mg.ha^{-1}$. This may be indicative that factors of high soluble salts (Epstein, 1975; Guidi et al., 1981), phytotoxicity of heavy metals (Page et al., 1972; Bingham et al., 1979; Valdares et al., 1983) and immobilization of available N by high C:N ratio did not have a significant effect on tomato yield at these application rates.

Highest yield obtained with PM are consistent with previous findings for cauliflower (Singh et al., 1970), tomato (Morelock and Hall, 1980) and strawberry (Hitz, 1951; Albregts and Howard, 1981). The yields obtained with poultry manure in all fruit size categories and the total yield were higher than those obtained with SS. These results are in agreement with previous findings by Cheung and Wong (1983). As observed for SS, increases in PM rate increased the tomato yield. Consequently, the high rate of PM used was not sufficient to produce NH_3 at a toxic level (Siegel et al., 1975) or increase the soluble salt concentrations, causing a foliage burn (Shortall and Liebhardt, 1975; Albregts and Howard, 1981) which may reduce the crop development and production.

In 1982, average fruit yields for main effect of organic amendments (SS and PM) at two fertilizer levels of 1400 and 2800 $kg.ha^{-1}$ were 36, 43 and 57% higher than those observed for F0 for total yield or for fruit yield in size categories 2 and 3, respectively. For the same comparisons in 1983, increases of 33, 35 and 88% were observed for total yield and fruit size categories 2 and 3, respectively. In addition, when PM and SS were utilized without application of fertilizer, these amendments gave tomato yield similar to those obtained with F0. These results are in agreement with previous reports (Sims and Boswell, 1980; Morelock and Hall, 1980). However, the present study did not agree with work by Sjorgren (1977) which pointed out that in no instance did the addition of sludge increase corn, tomato and beet yields to the same extent as did fertilizer alone, probably due to K deficiency.

According to the 1982 data, increase in the fertilizer level from 1400 to 2800 $kg.ha^{-1}$ did not affect significantly the tomato yield and did not interact with amendment sources. In this case, it is more appropriate to recommend utilization of PM and SS associated with low fertilizer level in order to get higher yields. However, according to present 1983 data, in order to get highest tomato yields, amendment with

PM at 11.2 $Mg.ha^{-1}$ associated with 1400 $kg.ha^{-1}$ of fertilizer or SS at 22.4 $Mg.ha^{-1}$ combined with 2800 $kg.ha^{-1}$ of fertilizer should be utilized.

Residual effect of treatments were observed in both years, however differences among treatments were more distinct in 1982 than in 1983. Cucumber plants that grew on residual PM and SS were darker green and the growth was greater than those treated with other amendments (FP, CM, BC and FO). Remarkable residual effects were noted in final cucumber yield when SS and PM treatments were utilized in 1982. The final yields produced on plots that received SS and PM were 445 and 378% higher than those observed when FO was used. However, in 1983, when SS and PM at 22.4 $Mg.ha^{-1}$ (same rate utilized in 1983) were applied, the residual effect on cucumber yield accounted for increases of 44 and 69%, respectively, compared to FO yield. These differences observed for residual treatment effect between years were primarily because the yields for SS and PM remained almost the same in both years, while the yield for FO increases 205% from 1982 to 1983 experiments. In addition, low nutrient leaching and higher initial soil fertility in the 1983 experiment are factors that could explain the residual effects in yield observed when FO were utilized. This residual effect is in agreement with other studies that have been made with multiple cropping of vegetables (Bryan and Dalton, 1974; Guilarte et al., 1975; Csizinszky, 1978; Everett, 1978) which pointed out that, by proper management of vegetable crops in Florida, such as tomato and pepper, it may be possible to double crop with either low or high management of vegetable or field crops.

The lower average of early and final fruit weight observed for cucumber fruit in 1983 than 1982 can be explained by the time interval between harvests. In 1983, this interval was 3 to 4 days while in 1982, it was 7 days. In 1982, residual effect of fertilizer level did not affect significantly the fruit yield of cucumber. However, in 1983, both early and final fruit yield gave a linear positive response to increase in fertilizer levels from 1400 to 4200 kg.ha^{-1}. But, when only 1400 and 2800 kg.ha^{-1} were considered, fertilizer level did not give a significant residual effect.

Additional application of N and K did not increase significantly the early and final cucumber yields. This is in agreement with Everett (1978) who found no response to fertilizer placement and rates utilized for re-fertilizing tomatoes or cucumber as a second crop after tomatoes. However, in that study, the hole-punch method for re-fertilizing was used and in this study fertilizer was applied in liquid form by a manual injector.

The data discussed above clearly support the idea that PM and SS can be used successfully for vegetable crops and the residual effect should be utilized by the practice of double-cropping. However, it would be unlikely that organic waste could be used to supply entirely, the total nutrient requirements of crops, because of the large amounts of these amendments that would have to be applied. The greatest potential value of these materials for vegetable production may be realized as they are used in combination with inorganic fertilizer.

Nitrogen Availability

Differences observed among amendment sources for tomato and cucumber yields can be associated with available total N determined during the growing season for both years. The available total N to the tomato crop was between 154 to 517 $mg.kg^{-1}$ at early season and 16 to 85 $mg.kg^{-1}$ late in the season of the first year. In the second year, available N ranged from 99 to 289 $mg.kg^{-1}$ at the beginning of the season and 14 to 135 $mg.kg^{-1}$ at late season. This available total N resulted from both organic N mineralization from organic amendments or soil and included that supplied in the fertilizer. The decreases in soil available N with time was due to plant uptake and possibly to losses through leaching and denitrification. This decrease varied with treatment. Amendment sources that produced the highest yields (SS and PM) also generated much more available total N than did FP, CM and FO in 1982 or BC and FO in 1983. These differences observed among amendment sources continued for soil samples taken in the cucumber experiment. From the above data, the evidence was that the available total N should account for corresponding differences in yields observed among amendment sources for both tomato and cucumber crops.

In both years, as the fertilizer level was increased, the available total N in soil increased. However, the tomato and cucumber yields were not necessarily increased by increased fertilizer level. Some cases in 1983 showed that yield decreased with increase in fertilizer. These variations in yield responses did not provide a clear definition for the productivity of amendment-treated soil as affected by fertilizer application rate. Magdoff and Amadon (1980) pointed out that highest corn yields were produced by combining 44 $Mg.ha^{-1}$ manure and 224 kg $N.ha^{-1}$. However, Gill and Meelu (1982) observed that 12 $Mg.ha^{-1}$ of manure could be substituted for 40 kg N as inorganic fertilizer. According to these results and many other in the literature, the response of crops to amendment sources was associated with inorganic fertilizer level and depended upon many factors such as soil type, amendment characteristics and climate. Consequently, it is difficult to use published data from other soils to solve a local problem. Hence, experimentation on the soil and local source of amendments would be necessary before proceeding to a general recommendation on use of amendments. This process would require the necessary input of amendment N and heavy metal content in decisions about use of such sources for vegetables.

Nitrate pollution of surface or ground water is one of the major concerns when organic amendments are applied in soil. In this study, the level of NO_3^--N increased with increase in the amendment rate in combination with fertilizer level. However, NO_3^--N concentration was not determined deeply enough through the soil profile in order to determine if contamination of the ground water occurred. According to Mathers et al. (1972; 1975) and Mathers and Stewart (1971), in a series of experiments where varying rates of manure were applied to soil, manure applications up to 22 $Mg.ha^{-1}$ supplied enough N for growing corn or sorghum without excess of NO_3^--N in the soil profile. High rates caused NO_3^--N accumulation of as much as 1,200 kg of NO_3^--N in 180 cm of soil when 224 $Mg.ha^{-1}$ of manure were applied. Long et al. (1975) and Doss et al. (1976) pointed out that, in the humid southeastern U.S., application of 45 $Mg.ha^{-1}.year^{-1}$ of manure can be utilized safely. However, Jackson et al. (1977) stated that rates of 22.4 $Mg.ha^{-1}$ of manure applied semi-annually were excessive from the standpoint of potential losses of a valuable N resource for crop production. Considering that the high rate of organic amendments applied in this study was not excessive (based on data presented above), leaching of nutrients from amendments was protected further from leaching by plastic mulch and by the practice of double cropping. Other workers (King and Morris, 1972; Hook and Kardos, 1977) concluded that minimal pollution of ground water should be expected where good soil management is practiced.

In both years, for all treatments, extracted NH_4^+-N concentration by 1 M KCl showed a decrease during the tomato cropping season. This decrease was more distinct from the first to second soil sampling. However, between years, the magnitude of this decrease was different. These observed differences should be due mainly to different patterns of mineralization than to plant uptake, because at the time of the second soil sampling, tomato plants were too small to account for this large decrease. In both years, as observed for NO_3^--N and available total N, highest extractable NH_4^+-N during tomato season were observed for PM and SS.

In 1982, data from ^{15}N analysis indicated that when PM and SS were applied, much more extractable NH_4^+-N in the soil was derived from other sources (amendment itself or from soil) than from the fertilizer. This obviously was due to the higher dilution of fertilizer N by PM and SS as compared to that by FP, CM or FO.

Soil Reaction, Electroconductivity and Moisture

Electrical conductivity values decreased during the growing season in both years and were significantly affected by amendment sources and fertilizer levels. While this might be due to the leaching of soluble salts, it was more likely caused by uptake by plants. Sewage sludge and PM amendments gave the highest EC values. Liebhardt and Shortall (1974) pointed out that heavy rates of PM applied to sandy Coastal Plain soils resulted in higher EC values and these were primarily associated with a high concentration of K in the soil solution. In this study, soil EC values for the 1983 tomato experiment were significnatly correlated mainly with NH_4^+-N, NO_3^--N, K and Cl. Tomato or cucumber yields in this study was not affected apparently by electrical conductivity (soluble salts) as reported by Shortall and Liebhardt (1975) for corn and Stewart and Mathers (1973) for sorghum. However, it should be pointed out that the highest amendment rate utilized in this study was much lower than rates utilized in both above investigations.

Another point suggesting that EC did not affect the cucumber and tomato yields in this experiment was the fact that values for EC observed during the cropping season were lower than values reported by Black (1968) and Bohn et al. (1979) which affected a decrease in yield of cucumber and tomato (EC = 10 $dS.m^{-1}$ for tomato and EC = 4 $dS.m^{-1}$ for cucumber).

Values for soil pH observed during tomato cropping were highest in 1983. The same trend was observed in soil samples taken at the beginning of the cucumber season. For both years and crops, the addition of PM and SS gave higher pH values than did FO in all soil samplings. This result was consistent with previous findings by Olsen et al. (1970), Premi and Cornfield (1971); Lund and Doss (1980); Terry et al. (1981) who reported increase in soil pH by addition of manure or sewage sludge.

In this study, amendment sources that resulted in highest values of soil pH had highest nitrification rates. Most observations generally indicate an arbitrary lower limit for nitrification to be pH 4.0. Obvious changes in nitrification were noted with pH in the 4 to 6 range whereas pH-independent nitrification was noted in the range 6 to 8

(Weber and Gainey, 1962; Chase et al., 1968; Sarathchandra, 1978). Values for soil pH in this study, especially for SS and PM, were in the appropriate range for nitrification. As mentioned before, these two treatments were those that had the highest NO_3^--N production.

Organic amendments showed a slight tendency to hold more water than did inorganic amendments. However, at the majority of soil sampling dates, no statistical difference among treatments was observed. Measurement of water retention curves for the different amended soils was not made. In the field, water use by the crops and changes in soil physical properties related with water should be responsible for soil water variability between treatments. Others have failed to find increase in water retention by soil amendments (Epstein et al., 1976; Gupta et al., 1977; Salter et al., 1965).

Carbon Dioxide Evolution

In both years, laboratory studies showed that cumulative CO_2-C evolution was quite similar at the end of incubation period for PM, SS and FO amendments. However, the curve shapes for each amendment were different as expected. In 1982, soil samples were air-dried before the incubation period while, in 1983, field-moist soil samples were utilized.

In 1982, CO_2-C evolved from the soil containing amendments ranked in the following order: PM > SS > FP > CM or FO. This sequence partially differed from that observed by Rothwell and Hortenstine (1969) in which SS > PM > garbage compost > CM. However, other researchers reported that rapidity and nature of decomposition of organic residues under aerobic conditions depended primarily upon the composition of the particular organic residue (Tenney and Waksman, 1929; Martin, 1933;

Castellanos and Pratt, 1981). In 1983, increase in the amendment application rate increased the CO_2-C evolution. This was in agreement with work by Tester et al. (1977).

The cumulative CO_2-C evolution can be related with rate of decomposition of organic material. According to the above findings, PM used in this study was the organic amendment that showed faster decomposition and, consequently, more release of nutrients from the other organic amendments or from the soil itself.

Soil Organic Matter and Cation Exchange Capacity

Significant differences observed among treatments in 1983 for OM and CEC were more distinct than in 1982. One reason for this was that only five degrees of freedom were associated with the error term in 1982 treatments compared to 10 for the error term in 1983. In general, when organic amendments were utilized, values for OM were higher than values observed for inorganic amendments (FO in 1982 or BC and FO in 1983). The CEC in both years was increased by organic treatments as might be expected from increase in soil OM. Poultry manure and SS amendments had the highest values for OM and CEC. These results are in agreement with previous reports (McIntosh and Varney, 1973; Mathers and Stewart, 1974; Epstein et al., 1975; Meek et al., 1982).

Application of BC did not improve the CEC as expected, perhaps due to the low amount of this amendment utilized.

Ion Concentration in Soil Water and Mehlich I Extracts

With most soil tests, ions present in water extracts are rarely determined, the exception being that saturated extracts are analyzed in several laboratories. As pointed out by Mengel and Kirby (1979), the concentration of the ions species in the soil solution (water-saturated extract) can differ widely depending on the soil properties and soil moisture. Fried and Shapiro (1961) observed that acid soils generally are lower in ionic concentration than more neutral soils and cited values of 3.4, 1.9, 0.7, 0.007, and 1.1 mMol for Ca, Mg, K, P, and Cl, respectively, for water extract in acid soil. These values are much lower than those values found in this study, possibly because nutrients were added and mulching was used so that less leaching would be expected. However, concentrations of nutrients in the water extract in this study were close to values observed by Marlowe and Cornell (1977) for tomato culture in Florida and Liebhardt and Shortall (1974) for sandy Coastal Plain soils when poultry manure was applied. In 1982, for all amendment sources, soluble nutrients decreased during the cropping season. However, in 1983, these nutrients (except Cl which decreased with time) had much more fluctuations during the season depending on which treatment was used. These changes and fluctuations, including variability, must be considered as the combined result of the supplying power of each nutrient by the soil and the amendments that is countered by the removal of nutrients through leaching and by plant uptake. Such reactions determine the nutrient level in soil solution. In both years, there were also large differences in the concentrations of monovalent and divalent cations that were water extractable, which was partly indicative of the relative bonding energy of divalent compared to monovalent cations. In this soil, which is dominated by CEC from organic matter, the apparent water solubility was $Ca^{2+} < Mg^{2+} < NH_4^+ < K^+$ which agrees, partially, with a similar relationship between cations found by Fiskell et al. (1978) for pepper. These same authors suggested that soluble nutrient composition from a 1:1 soil:water mixture can supplement soil test data obtained by the Mehlich I method, particularly for K^+ and NH_4^+-N analysis.

Water-extractable Ca^{2+}, Mg^{2+}, K^+, and NH_4^+-N concentrations were, as expected, lower than those obtained with Mehlich I extract. The latter reagent gave values for Ca and Mg approximately 20 and 8 times higher, respectively, than those by water. This large amount of Ca and Mg extracted can be associated with exchangeable Ca and Mg.

For each amendment source, the overall cation concentration means taken for all soil sampling dates for both water and Mehlich I extracts were compared in order to establish the percentage of exchangeable cations that were water soluble. For soil with SS, soluble Ca^{2+}, Mg^{2+}, K^+, and NH_4^+-N concentrations were 5, 13, 63, and 52%, respectively, of that obtained by Mehlich I extract. For soil with PM, corresponding values were 3, 11, 57, and 45%. When BC was the amendment, corresponding above nutrients were 4, 17, 60, and 55% of those by Mehlich I reagent. Similarly for FO, the values were 3, 8, 53, and 55% those by the Mehlich I extract, respectively. These data clearly showed that K^+ and NH_4^+-N were much more water extractable than Ca^{2+} or Mg^{2+} as mentioned earlier.

For all treatments in 1983, levels of Ca, Mg, K, and P extractable by Mehlich I reagent were in the adequate range to plant growth according to interpretations followed by the IFAS Soil Testing Laboratory (Rhue and Kidder, 1984).

The use of Mehlich I reagent as a soil test reagent for Cd, Ni, Zn, and Mn has not previously received attention. Recently, analysis of Mn, Zn, and Cu was done by IFAS Soil Testing Laboratory as non-routine analysis. Application of organic amendments, specially sewage sludge in the soil, requires that heavy metals be monitored due to the potential for accumulation in the soil and possible resultant phytotoxicity and metal uptake by plants. In this study, soil amendment with SS had much more Cd, Ni, and Zn concentrations in Mehlich I extract than did the other three amendment sources. These data were in agreement with other research (Page et al., 1972; Baker et al., 1975; Jones et al., 1975; Bingham et al., 1979; Valdares et al., 1973). However, concentrations of those three nutrients in the present study were not high enough to cause phytotoxicity to plant growth according to the above-cited researchers.

Nutrient uptake in leaf and fruit

Undoubtedly, plant analysis provides an available tool in the determination of the nutritional status of various crops. In contrast to soil analysis, tissue analysis reflects nutrient uptake conditions of the soil. In most cases, leaf or tissue analytical data correlated fairly well with soil tests (Hipp and Thomas, 1968). In both years of this study, for tomato and cucumber crops, utilization of SS and PM increased the availability of both macro- and micronutrients in the soil. In general, leaf and fruit samples taken from plants grown with these two amendments showed higher uptake of nutrients than did plants grown with the other amendments. This is in agreement with Sabey and Hart (1975) who observed that a sludge application rate of 25 $Mg.ha^{-1}$ or more supplied ample nutrients for wheat growth under low-yielding field conditions. King and Morris (1972) also found that uptake of P, Ca, Mn, Cu and Zn by rye increased with application of sewage sludge. Other studies (Coker, 1966; Kardos et al., 1977; King et al., 1976; Touchton and Boswell, 1975) have shown that organic wastes can supply adequate amounts of macronutrients for crop growth and that tissue concentration of N, P, Ca, and Mg tend to increase with the loading rate of waste. This trend was observed in this study in 1983 when two amendment rates were used. Also in this study, macro- and micronutrients concentrations observed in leaf and fruit tissue for all treatments were apparently well above the levels in tissue showing deficiency symptoms (Wallace, 1961; Chapman, 1966). In addition, soil amended with PM or SS had concentrations of nutrient in leaf and fruit of tomato and cucumber in the adequate range for plant growth, according to War (1967) and Tanaka et al. (1974).

In 1982 experiments, ^{15}N-depleted ammonium sulfate was used to determine the percentage of plant N derived from the fertilizer. The percentage of tissue N coming from fertilizer N showed an inverse trend to that observed for total N in tomato leaf and fruit (see Figs. 4 and 5). Increase in total N concentration was associated with a decrease in percentage of N coming from fertilizer. Under SS and PM treatments, the percentage of leaf and fruit N coming from fertilizer was lower than those found for other treatments, specially for FO. Obviously this was due to the higher dilution of fertilizer N when SS and PM were utilized so that average means between these two treatments were considered in regard to the percentage of N that came from fertilizer. These means averaged over all three tomato leaf and fruit samplings were 8.5% and 10.3%, respectively. When FO was utilized, the percentage of N that came from fertilizer was 34.4% in leaf and 33.1% in fruit. Other studies have shown the above-ground portion of corn contained 15 to 68% fertilizer-derived N (Broadbent and Carlton, 1978; Olson, 1980). In tissue of sugarbeet storage roots plus tops, 21 to 23% of the N was derived from that added in fertilizer (Hill et al., 1981; Hill et al., 1978). Broadbent et al. (1980) showed tomato contained 34% of N from fertilizer. Fiskell and Locascio (1983) pointed out that 22 to 30% of the N in tomato plant tops came from fertilizer N. They noted that the fruit harvested at 9, 11 and 13 weeks after initial fertilization contained 72.5, 62.9 and 48.8% of the N derived from fertilization.

Percentage of N that came from the fertilizer in cucumber tissue was very low for all amendment sources. These data showed that very little of the N applied for tomato remained for cucumber tissue.

As pointed out above, the concentration of micronutrients (Zn, Fe, Mn, Cu) in leaf and fruit of tomato and cucumber was in the adequate range for plant growth without any visual toxic effect. However, when SS was applied, concentration of these nutrients, including Cd, was higher than observed for other amendment treatments. This effect was more distinct in the 1983 experiment, as expected, because the initial chemical composition of the SS utilized in 1983 was much higher in these nutrients than the SS used in 1982.

Numerous non-edible horticultural crops have been grown successfully in soil where sewage sludge was applied. However, in the production of vegetable crops, specially the edible portion, consideration must be given to the influence of sewage sludge on both metal accumulation and crop yield. The term "Soil-Plant Barrier" has been used to describe the processes by which the human food chain is protected from most of the heavy metals found in sewage sludge (Chaney, 1980). Insolubility of metals in soil or sludge type limits root accumulation of Pb, Cr, Hg and Fe (Chaney, 1980). Phytotoxicity from Zn, Cu, Ni, Mn, Co and B limits the impact of these metals on the food chain (Chaney and Giordano, 1977; Foy et al., 1978; Chaney, 1980). However, the "Soil-Plant Barrier" does not provide adequate protection of food-chain plants against excess Cd accumulation (Foy et al., 1978; Chaney, 1980). In the present study, mainly in 1983, the concentration of Cd in tomato leaf when SS was used was higher than that in the reported range of 0.2-0.8 mg.kg^{-1}, which is the concentration of Cd typically found in plants (Allaway, 1968). However, tomato fruit samples from these treatments had Cd concentration much lower than that observed in leaves. These results are in agreement with previous reports by Dowdy and Larson (1975) which investigated the extent of sludge-borne metal accumulation in the edible tissue, of seven vegetable crops. They reported small but significant increases in Cd content of edible fruit, tuber, and root tissue from soil amended with sludge. However, metal accumulation was much greater in the leaf tissue. Giordano et al. (1975) also found that higher metal levels occurred in vegetative tissue than storage tissue for different vegetable species.

Field experiments have shown that only low-metal sludges or sludge compost can be used safely in the production of edible crops (Chaney and Giordano, 1977). The Environmental Protection Agency (1980) recommends that the annual application of Cd from waste does not exceed 0.5 kg.ha^{-1} on land used for production of tobacco, leafy vegetables, or root crops grown for human consumption. In this study, the Cd concentration in the sewage sludge was 12 and 55 mg.kg^{-1} in 1982 and 1983, respectively. Consequently, application of this amendment at high rate, 22.4 Mg.ha^{-1}, was equivalent to applying 0.53 and 2.46 kg.ha^{-1} of Cd in soil for 1982 and 1983, respectively. Although the amount of Cd applied is above that recommended by EPA (1980), concentration of this element in tomato and cucumber fruit was nearly that of median Cd values in different food classes (Hallenbeck, 1979).

CONCLUSIONS

In both years, tomato fruit yields in size categories 2 and 3 and for total fruit yield were significantly increased by incorporation of organic amendments in the bed. The first year, fruit yields of 90 and 100 $Mg.ha^{-1}$ were obtained with either SS or PM compared to 70 $Mg.ha^{-1}$ with FO treatment. This was attributed to substantially higher soil NO_3^--N during the growing season from these amendments. Soil and tissue N were found to contain much less N derived from the ^{15}N-depleted ammonium sulfate than from either the soil or amendments plus soil. Even through the full-bed mulch protected the fertilized soil from direct contact with heavy rainfall, yet when water stood between the beds this permitted soluble salts to move during drainage of the beds and middles.

Residual effect of SS and PM had an outstanding effect on cucumber fruit yield than that from FP, CM or FO treatments. This indicated that these two organic amendments were mineralized and nitrate produced to a much greater extent than for soil alone or with FP and CM amendments. Very low amounts of N in cucumber leaf and fruit tissue were derived from the fertilizer. This confirmed that the fertilizer N had been depleted from the soil by plant uptake, possibly by denitrification and during loss by leaching. The CO_2-C evolved from SS and PM amendment of soil was greater than that for FP, CM or FO in treated soil. This indicated mineralization of organic amendments; these data on C evolution might also be assumed to be similar for NH_4^+-N and NO_3^--N production during incubation. This process of available N production by PM or SS was evidently sufficient for high yields of tomato and cucumber nutrition and was likely to exceed that from mineralization of FP, CM or FO amendment.

The second year, SS and PM amendments were superior to BC or FO amendment for both tomato and cucumber fruit production. The highest tomato fruit yields were 131 and 118 $Mg.ha^{-1}$ observed when PM at 11.2 $Mg.ha^{-1}$ was associated with 1400 $kg.ha^{-1}$ of fertilizer and SS at 22.4 $Mg.ha^{-1}$ was associated with 2800 $kg.ha^{-1}$ of fertilizer, respectively.

Early cucumber fruit yield ranged from 11.9 to 23 $Mg.ha^{-1}$ and final yield from 21.8 to 41.7 $Mg.ha^{-1}$. The highest residual effect of amendments was obtained for PM applied at 22.4 $Mg.ha^{-1}$ associated with 2800 $kg.ha^{-1}$ of fertilizer. However, the lowest residual effect was observed for SS at 11.2 $Mg.ha^{-1}$ without application of fertilizer for the tomato crop. Application of liquid fertilizer (NK) on half of the plot area increased the early and final cucumber fruit yield only by 1.4 to 2.0 $Mg.ha^{-1}$, respectively, compared to the half without further fertilizer application.

Available N in soil, N content in tomato and cucumber leaf, and in fruit tissue from treatments receiving organic amendments (SS and PM) compared favorably with soil and tissue levels of N obtained from inorganic amendments. Soil pH, EC, OM and CEC showed some tendency to be higher when organic amendments was utilized compared to that for inorganic amendments. Cumulative CO_2-C evolution from the soil containing amendments ranked PM > SS > BC > FO.

Although the total Cd concentration in SS applied in the soil in 1983 was 55 $\mu g.kg^{-1}$, Cd concentration in tomato fruit was nearly that of published median Cd values in different food classes. With SS, the average Cd level in tomato leaf and fruit was 4.5 $mg.kg^{-1}$ and 25.6 $\mu g.kg^{-1}$, respectively. This indicated that Cd transport into the tomato fruit was much less than that into the tomato leaves.

It would be unlikely that organic amendments (SS and PM) could be used to supply the total nutrient requirements of crops, because of the large amounts that have to be applied. The greatest potential value of these materials for tomato and subsequent cucumber crops may be realized when previous composition of these amendments were known and applied in combination with appropriate grade of inorganic fertilizer to supply the known nutrient requirements of the crop.

APPENDIX

Table A-1. Profile description of Mulat sand.‡

LOCATION: Alachua County, Florida; Horticulture Unit, 150' east of main road, 0.75 mile north of State Road 232.

PARENT MATERIAL AND LAND FORM: Unconsolidated marine sediments.

SLOPE AND ELEVATION: Nearly level with less than 2% gradient; approximately 170'.

DRAINAGE AND PERMEABILITY: Poorly drained; rapid in A horizon and moderate to moderately rapid in B2tg horizon.

VEGETATION AND USE: Native vegetation and cultivated crops including pepper.

HORIZON	DEPTH	DESCRIPTION
Ap	0.20 cm (0-8")	Dark gray (10 YR 4/1) sand; weak fine granular; very friable; many fine roots; medium acid; abrupt smooth boundary. 2524.
A21	20-38 cm (8-15")	Grayish-brown (10 YR 5/2) sand; few weak faint brown mottles in upper portion of horizon; single grain; loose; medium acid; gradual wavy boundary. 2525.
A22	38-53 cm (15-21")	Grayish-brown (10 YR 5/2) sand; few medium faint light brownish-gray and few medium distinct brownish-yellow mottles; approximately 2% nodules of soft ironstone and phosphate fragments 2-35 mm in size; single grain; loose; medium acid; abrupt wavy boundary. 2526.
B2tg	53-68 cm (21-27")	Light brownish-gray (10 YR 6/2) sandy loam; many medium and coarse prominent yellowish-red mottles; weak medium subangular blocky; friable; medium acid; clear wavy boundary. 2527.
B3g	68-117 cm (27-46")	Gray (10 YR 6/1) loamy sand; moderate medium granular; very friable; very strongly acid; phosphate pebbles in lower portion of horizon; clear wavy boundary. 2528.
Cg	117-203 cm (46-80")	Light gray (10 YR 7/1) sand; many medium and coarse distinct white mottles and pebbles; single grain; loose, very strongly acid. 2529.

REMARKS: Some phosphatic pebbles crush with heavy finger pressure. Soil would be in Arenic subgroup if it were in Soil Taxonomy.

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‡ Carlisle, W.V. et al. (1981).

Table A-2. Chemical properties of soil utilized in 1982 and 1983 experiments before application of treatment.

Soil	Year	depth (cm)	pH H_2O (1:1)	Org. Matter $g.kg^{-1}$	EC $dS.m^{-1}$	Total N $g.kg^{-1}$	Mehlich I ($mg.kg^{-1}$)			
							Ca	Mg	K	P
Mulat sand	1982	0-20	5.50	20.5	0.09	1.44	1840	145	201	98
Mulat sand	1983	0-20	6.80	22.6	0.25	2.20	2380	225	229	145

Table A-3. Analysis of variance for the effect of amendment and fertilizer level on forms of soil N extracted at four dates after application of treatments. Tomato experiment, 1982.

Source of Variation	df	Water extract		KCL extract	Available total N	N from fertilizer
		NO_3^--N	NH_4^+-N	NH_4^+-N		
		Mean squares				
			7 days after application of treatments			
Blocks	3	188.3***	1465.6	1634.9	14948.9	186.9
Amendment (A)	4	657.7***	62063.6***	58684.1***	250449.9***	500.0**
Fert. level (F)	1	319.3**	28219.4***	27717.5***	124144.1***	5705.8***
AxF	4	36.3	3868.6***	4170.5*	15689.1**	845.0***
Error	27	24.4	940.5	1302.6	2873.9	123.4
			40 days after application of treatments			
Blocks	3	14.4	21.4	23.8	102.9	29.9
Amendment (A)	4	4169.2***	1181.4***	7524.3***	27560.1***	46.8***
Fert. level (F)	1	524.4**	142.2**	504.4**	3281.5***	190.4*
AxF	4	66.2	23.2	24.8	243.3	9.4
Error	27	43.2	12.4	74.8	143.8	7.0
			70 days after application of treatments			
Blocks	3	24.4	34.7**	27.6	206.8*	
Amendment (A)	4	28720.2***	337.3***	264.0**	40836.6***	
Fert. level (F)	1	2018.3***	141.7***	177.5**	4921.7***	
AxF	4	126.4*	10.7	26.6	136.6	
Error	27	45.3	5.7	21.3	67.8	
			110 days after application of treatments			
Blocks	3	31.6	0.7	2.2	45.9	
Amendment (A)	4	3152.0***	145.2***	243.9***	6806.8***	
Fert. level (F)	1	217.6**	13.9***	69.1***	87.3*	
AxF	4	75.3*	1.4	1.5	48.9	
Error	27	18.5	0.4	1.8	27.1	

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

Table A-4. Analysis of variance for the effect of amendment and fertilizer level for soil pH, EC and soil moisture at four dates after application of treatments. Tomato experiment, 1982.

Source of variation	df	pH	EC	Moisture	pH	EC	Moisture
		Mean square					
		7 days^			40 days^		
Blocks	3	0.45***	0.62	4790.8**	0.50**	0.41	1240.1**
Amendment (A)	4	1.51***	16.01***	1061.0	0.68***	11.01***	345.2
Fertilizer level (F)	1	0.01	3.84**	95.7	0.02	1.82**	1.4
AxF	4	0.08	0.63	617.7	0.03	0.40	279.1
Error	27	0.05	0.34	1184.4	0.08	0.30	245.2
		70 days^			110 days^		
Blocks	3	0.1	0.41	1240.1***	0.35***	2.01**	1378.1**
Amendment (A)	4	0.24**	11.01***	345.2	0.19**	2.81***	596.1*
Fertilizer level (F)	1	0.12	1.81	1.2	0.10	0.10	7.2
AxF	4	0.05	0.42	279.0	0.05	0.31	205.1
Error	27	0.04	0.31	245.0	0.04	0.32	214.2

*, **, ***F value significant at the 5%, 1% and 0.1% level, respectively.
EC = Electrical conductivity.
^Days after application of treatments.

Table A-5. Analysis of variance and main effect of amendment and fertilizer level on cumulative CO_2-C evolution. Tomato experiment, 1982.

Source of variation	df	Days of incubation 3	6	13	20	27	41	60
		Mean squares						
Amendment (A)	4	0.0389***	0.1030***	0.0960***	0.1092***	0.1091***	0.1065***	0.0968***
Fert. level (F)	1	0.0010	0.0049**	0.0174**	0.0211**	0.0328***	0.0403***	0.0534***
AxF	4	0.0001	0.0007	0.0014	0.0018	0.0018	0.0018	0.0027
Error	10	0.0002	0.0004	0.0011	0.0016	0.0016	0.0025	0.0026
		g CO_2-C.kg^{-1} soil						
Amendment‡								
SS		0.29b[y]	0.50b	0.62b	0.69b	0.72b	0.74b	0.76b
PM		0.37a	0.62a	0.71a	0.78a	0.81a	0.84a	0.86a
FP		0.20c	0.33c	0.47c	0.53c	0.56c	0.58c	0.61c
CM		0.18c	0.29d	0.40d	0.43d	0.46d	0.48d	0.52d
FO		0.13d	0.24e	0.35d	0.41d	0.44d	0.48d	0.50d
F value		***	***	***	***	***	***	***
Fert. level ($kg.ha^{-1}$)								
1400		0.22	0.38	0.48	0.53	0.56	0.58	0.60
2800		0.24	0.41	0.54	0.60	0.64	0.67	0.70
F value		NS	**	**	**	***	***	***

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[y] Amendment mean separation within columns by Duncan's Multiple Range Test, 5% level.

‡See Table 3 for abbreviations.

Table A-6. Analysis of variance for the effect of amendment and fertilizer level on Ca, Mg, K, P and Cl concentration in soil water extract at four dates after application of treatments. Tomato experiment, 1982.

Source of variation	df	Ca	Mg	K	D	Cl
		------------------ Mean square ------------------				
		7 days after application of treatments				
Blocks	3	19372.5**	158.0	262.0	0.171**	20900.1**
Amendment (A)	4	16023.1**	3408.1***	14101.8***	0.091	45196.2***
Fertilizer level (F)	1	4792.4	80.1	2402.5**	0.007	640.0
AxF	4	3677.6	20.3	501.5	0.003	1521.2
Error	27	3362.2	217.3	442.6	0.040	3694.4
		40 days after application of treatments				
Blocks	3	4454.1*	377.2*	1050.7	0.34***	4127.0
Amendment (A)	4	37742.1***	4620.6***	8026.1***	0.18***	52639.7***
Fertilizer level (F)	1	10925.2**	15.6	2052.1	0.03	2146.2
AxF	4	431.2	40.8	2387.8	0.01	1058.7
Error	27	1082.8	88.3	848.4	0.03	3294.6
		70 days after application of treatments				
Blocks	3	22786.4***	33.1	3756.2*	0.41***	8151.3**
Amendment (A)	4	10112.1***	3671.2***	11502.1***	0.20***	7318.4**
Fertilizer level (F)	1	489.5	21.4	4083.2	0.03	2295.5
AxF	4	629.2	144.4	49.4	0.05	707.2
Error	27	1642.0	49.2	1164.1	0.04	1596.1
		110 days after application of treatments				
Blocks	3	639.5	486.7**	639.5	0.10**	4457.6*
Amendment (A)	4	7844.5***	6271.2***	7844.5***	0.17***	10128.7***
Fertilizer level (F)	1	9021.1***	40.2	9021.1***	0.14**	330.6
AxF	4	880.7	57.3	880.7	0.02	40.0
Error	27	610.9	95.4	610.9	0.02	1418.4

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

Table A-7. Analysis of variance for the effect of amendment and fertilizer level on tissue N concentration and N from fertilizer for tomato leaf and fruit at three dates after transplant. Tomato experiment, 1982.

Source of variation	df	Total N	N from fertilizer	Total N	N from fertilizer
		Mean square			
		Leaf		Fruit	
		41 days after transplant		63 days after transplant	
Blocks	3	21.4	46.3**	9.7*	2.5
Amendment (A)	4	30.1***	198.1***	54.6**	32.3***
Fert. level (F)	1	94.8*	143.0***	11.9*	15.3*
AxF	4	16.3	8.3	2.2	1.0
Error	27	25.9	9.0	2.6	2.9
		63 days after transplant		85 days after transplant	
Blocks	3	31.8*	5.8*	2.0	7.8
Amendment (A)	4	545.5***	36.2***	11.1*	28.3**
Fert. level (F)	1	150.5***	105.4***	29.1**	29.3*
AxF	4	7.4	4.0	8.2	7.1
Error	27	10.4	1.5	3.1	5.1
		93 days after transplant		106 days after transplant	
Blocks	3	42.2	8.2**	52.0**	8.4*
Amendment (A)	4	489.1***	13.3***	55.1***	53.9***
Fert. level (F)	1	93.3*	38.6***	11.1	20.5**
AxF	4	14.7	0.2	3.2	2.7
Error	27	14.7	1.2	4.7	1.9

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

Table A-8. Analysis of variance for the effect of amendment and fertilizer level on Cd, Mn, Zn, Fe, Al and Cu concentration of tomato leaf and fruit at three dates after transplant. Tomato experiment, 1982.

Source of variation	df	Leaf						Fruitˆ				
		Cd	Mn	Zn	Fe	Al	Cu	Mn	Zn	Fe	Al	Cu
		Mean square										
		41 days after transplant							63 days after transplant			
Blocks	3	0.11**	7747**	74	110	5211	1.6	192**	34	88	486	1.3
Amendment (A)	4	0.09**	18180***	529***	944***	4441	24.0***	147**	45**	103	201	8.7**
Fert. level (F)	1	0.00	227	773***	5	7434	8.0	47	43	50	103	0.2
AxF	4	0.5	3544	73	361	3268	2.6	36	12	39	321	4.9
Error	27	0.02	1342	28	113	2883	1.4	37	14	71	199	2.0
		63 days after transplant							85 days after transplant			
Blocks	3	0.07	37863***	30	1627*	7798*	4.2	121**	135	11	121	3.4
Amendment (A)	4	0.08*	10946	53	1141	7371*	21.0**	170***	65	58	469*	10.1***
Fert. level (F)	1	0.08	746	152	110	185	0.3	294***	69	21	101	5.2*
AxF	4	0.05	3694	91	511	1826	3.3	14	37	27	294	1.2
Error	27	0.03	8597	197	526	2216	3.9	18	40	42	119	1.2
		93 days after transplant							106 days after transplant			
Blocks	3	0.02	506	94	54	325	1.2	33	14	321	75	1.9
Amendment (A)	4	0.33***	1607*	234*	3921***	1748*	44.7***	303***	105***	761**	23	17.3***
Fert. level (F)	1	0.22**	35	20	26	345	3.9**	20	1	267	116	0.0
AxF	4	0.01	271	107	180	548	0.5	4	3	97	68	1.0
Error	27	0.02	544	89	102	319	1.0	23	4	157	36	1.3

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

ˆAt 63, 83 and 106 days for Cd amendment, fert. level and interaction between them were not significant.

Table A-9. Analysis of variance for the effect of amendment and fertilizer levels on total N and proportion of the total N from fertilizer on leaf and fruit. Cucumber experiment, 1982.

Source of variation	df	Leaf		Fruit	
		Total N	N from fertilizer	Total N	N from fertilizer
		Mean square			
		40 days^		64 days^	
Block	3	10.1	0.46	2.0	0.51
Amendment (A)	4	262.1***	1.67***	215.5***	1.85***
Fertilizer level (F)	1	24.0	1.12*	0.0	2.98***
A x F	4	1.0	0.37	2.4	0.32
Error	27	7.5	0.19	5.4	0.13

^Days after transplanting.

***F value significant at the 0.1% level.

Table A-10. Analysis of variance for the effect of 21 treatments on tomato fruit yield. Tomato experiment, 1983.

Source of variation	df	Fruit yield (Mg.ha^{-1})				
		Size category				
		1	2	3	4	Total
		Mean square				
Block	2	570.7*	152.4	12.4	4.1	1432.2*
Treatment	20	144.3	142.6**	51.2***	4.7***	781.4*
Error	40	140.9	56.3	13.6	1.7	423.0
Contrast[+]						
		Inorganic amendment				
FO-L	1	79.8	52.0	103.2**	13.2**	146.1
FO-Q	1	116.6	24.8	22.0	2.3	485.1
BC-R	1	74.8	231.6*	12.9	0.0	726.3
BC-FL	1	25.4	54.1	1.1	2.0	222.1
BC-FQ	1	72.1	1.8	6.5	0.0	155.6
BC-RxFL	1	36.6	11.8	0.7	0.5	8.2
BC-RxFQ	1	49.90	0.9	0.9	3.7	26.0
		Organic amendment				
SS-R	1	19.1	104.7	44.5	3.0	530.1
SS-FL	1	283.8	144.3	0.3	0.0	867.6
SS-FQ	1	32.4	102.0	95.3**	6.9*	795.4
SS-RxFL	1	1.1	42.2	36.8	1.6	163.0
SS-RxFQ	1	18.0	40.2	20.8	2.6	281.0
PM-R	1	230.8	95.0	207.7	27.6***	202.2
PM-FL	1	202.7	65.0	17.3	5.4	251.5
PM-FQ	1	252.3	81.9	8.2	1.1	830.8
PM-RxFL	1	112.1	230.5*	58.1*	9.4*	1330.7
PM-RxFQ	1	620.5	629.2**	80.3*	0.1	3519.7**
		Amendment comparisons				
FO vs BC	1	6.5	10.8	1.8	0.2	0.4
SS vs PM	1	47.0	166.9	163.7**	11.9*	1298.4
OA vs IA	1	402.5	666.6**	140.4**	2.1	3504.7**

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

[+] See Table 2 in Material and Methods for abbreviations.

Table A-11. Analysis of variance for the effect of amendment sources with two fertilizer levels on tomato fruit yield. Tomato experiment, 1983.

Source of variation	df	Fruit yield ($Mg.ha^{-1}$) Size category 1	2	3	4	Total
Blocks	2	722.3**	333.0**	56.0**	8.0*	2599.5**
Amendment (A)	6	108.5	199.2**	107.7***	11.0***	981.7*
Fert. level (F)	1	139.8	6.8	15.5	3.6	11.3
A x F	6	238.3	216.7**	41.5**	1.9	1346.3**
Error	26	106.8	49.2	10.0	1.8	342.4

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

Table A-12. Analysis of variance for the effect of 21 treatments on soil N extracted at four dates after application of treatments. Tomato experiment, 1983.

Source of variation	df	Water extract		KCl 1 M extract	Mehlich I extract	Available Total N
		NO_3^--N	NH_4^+-N	NH_4^+-N	NH_4^+-N	
		Mean square				
				19 days after application of treatment		
Block	2	9.2	13.7	265.3	529.1	359.1
Treatment	20	2630.5***	2802.8***	11975.6***	21826.2***	8850.6***
Error	40	54.1	79.8	264.4	284.4	370.4
				48 days after application of treatment		
Block	2	1671.5	201.2	304.8	30.1	3382.2
Treatment	20	8660.3***	999.7***	2808.3***	2925.0***	17548.1**
Error	40	463.8	149.3	176.0	127.7	698.1
				80 days after application of treatment		
Block	2	47.8	39.4	96.1	113.7	192.6
Treatment	20	9381.0***	338.1***	2109.7***	1826.5***	17994.4***
Error	40	181.0	21.8	43.7	72.8	227.4
				111 days after application of treatment		
Block	2	180.1	6.5	0.1	4.7	177.8
Treatment	20	3720.0***	40.1***	171.2***	122.9***	4768.7***
Error	40	207.1	2.3	6.6	4.3	220.8

***F value significant at 0.1% level.

Table A-13. Significant contrasts mean square for soil N extracted at four dates after application of treatments. Tomato experiment, 1983.

Contrast+	df	NO_3^--N, water				NH_4^+-N, water				NH_4^+-N, 1 M KCl				Available total N			
		Days after application of treatments															
		19	48	80	111	19	48	80	111	19	48	80	111	19	48	80	111
		Mean square															
Inorganic amendment																	
FO-L	1	***	*	***	*	***				**				***	*	***	**
FO-Q	1													**	**		
BC-R	1	*	***											*			
BC-FL	1	***	***	**	**	***	***	**		***	**	**		***	***	***	**
BC-FQ	1		*														
BC-RxFL	1																
BC-RxFQ	1																
Organic amendment																	
SS-R	1		***	***	***					***	***	***		***	***	***	***
SS-FL	1	***	**	***	***	***	***	***	***	***	***	***	***	***	***	***	***
SS-FQ	1										*	***	*				
SS-RxFL	1	**		***					***		*	***	***				**
SS-RxFQ	1									**	***	***		**			
PM-R	1	***	***	***	***	***	**	***	*	***	***	*		***	***	***	***
PM-FL	1	***	**	***	***	***	***	***		***	***	***	***	***	***	***	***
PM-FQ	1																
PM-RxFL	1			**				***	***			**				***	
PM-RxFQ	1						***									*	
Amendment comparisons																	
FO vs BC	1		***												***		
SS vs PM	1	*	**	***	*	*	*		***	***	***	***	***	***			
OA vs IA	1	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

+See Table 2 in Material and Methods for abbreviations.

Table A-14. Significant contrast mean square for soil pH and EC at four dates after application of treatments. Tomato experiment, 1983.

Contrast+	df	pH				EC			
		Days after application of treatments							
		19	48	80	111	19	48	80	111
		Mean square							
		Inorganic amendment							
FO-L	1					***	***	***	***
FO-Q	1							*	***
BC-R	1		*						
BC-FL	1			*	*	***	***	***	***
BC-FQ	1								
BC-RxFL	1								
BC-RxFQ	1								
		Organic amendment							
SS-R	1	*					*	*	
SS-FL	1			**	*	***	***	***	***
SS-FQ	1						**	**	
SS-RxFL	1								
SS-RxFQ	1							**	
PM-R	1						**	**	
PM-FL	1					***	***	***	***
PM-FQ	1								
PM-RxFL	1								
PM-RxFQ	1							*	
		Amendment comparisons							
FO vs BC	1			*			*		*
SS vs PM	1	*	*	*	**		***		
OA vs IA	1	***					***	***	***

*, **, *** Fvalue significant at the 5%, 1% and 0.1% levels, respectively.
+See Table 2 in Material and Methods for abbreviations.

Table A-15. Analysis of variance for the effect of amendment sources and fertlizer level on soil pH, EC and moisture when fertilizer at 1400 and 2800 kg.ha^{-1} were considered at four dates after application of treatments. Tomato experiment, 1983.

Source of variation	df	pH	EC	Moisture	pH	EC	Moisture
		---------- Mean square ----------					
			19 days^			48 days^	
Block	2	0.58	0.14	609.1*	1.64***	0.68***	376.1
Amendment (A)	6	0.68***	1.18***	244.5	0.17	2.83***	258.8
Fert. level (F)	1	0.01	6.98***	120.4	0.00	8.35***	64.8
AxF	6	0.21	0.11	159.4	0.05	0.13	234.6
Error	26	0.10	0.05	139.2	0.07	0.05	235.1
			80 days^			111 days^	
Block	2	0.88***	0.02	400.6**	1.41***	0.03	539.5
Amendment (A)	6	0.21***	0.64***	123.1	0.18**	0.76***	686.5
Fert. level (F)	1	0.09	1.79***	43.3	0.17	3.06***	144.5
AxF	6	0.08	0.07	23.2	0.04	0.04	163.7
Error	26	0.03	0.04	53.6	0.05	0.08	275.0

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

^Days after application of treatments.

Table A-16. Analysis of variance and main effect of amendment and fertilizer level on cumulative carbon dioxide production. Tomato experiment, 1983.

Source of variation	df	Days of incubation 3	10	17	24	38	60
		Mean square					
Amendment (A)	6	0.0098***	0.0427***	0.0716***	0.0905***	0.1065***	0.1365***
Fertilizer level (F)	1	0.0025	0.0002	0.0023	0.0052	0.0122*	0.0187*
A x F	6	0.0011	0.0008	0.0018	0.0026	0.0032	0.0035
Error	14	0.0002	0.0008	0.0015	0.0018	0.0020	0.0036
		$g.CO_2$-$C.kg^{-1}$ of dry soil					
Amendment[+]							
SS_1 (11.2 $Mg.ha^{-1}$)		0.14c	0.28c	0.37b	0.44b	0.53c	0.63c
SS_2 (22.4 $Mg.ha^{-1}$)		0.17b	0.33b	0.42b	0.50b	0.60b	0.73b
PM_1 (11.2 $Mg.ha^{-1}$)		0.17b	0.30bc	0.39b	0.47b	0.57bc	0.69bc
PM_2 (22.4 $Mg.ha^{-1}$)		0.24a	0.48a	0.62a	0.71a	0.81a	0.96a
BC_1 (1.12 $Mg.ha^{-1}$)		0.10cd	0.19d	0.24c	0.29c	0.36d	0.43d
BC_2 (2.24 $Mg.ha^{-1}$)		0.12d	0.21d	0.26c	0.31c	0.40d	0.49d
FO		0.11d	0.20d	0.25c	0.30c	0.37d	0.46d
F value		***	***	***	***	***	***
Fert. level ($kg.ha^{-1}$)							
1400		0.14	0.28	0.36	0.42	0.50	0.60
2800		0.16	0.28	0.38	0.45	0.54	0.65
F value		NS	NS	NS	NS	*	*

NS, *, **, ***F value not significant, significant at the 5%, 1% and 0.1% levels, respectively.

[y] Amendment mean separation within column by Duncan's Multiple Range Test, 5% level.

[+] See Table 20 for abbreviations.

Table A-17. Analysis of variance for the effect of 21 treatments on Ca, Mg, K and Cl concentration in soil water extract at four dates after application of treatments. Tomato experiment, 1983.

Source of variation	df	Soil water extract			
		Ca	Mg	K	Cl
		---------- Mean square ----------			
		19 days after application of treatment			
Block	2	53.5	1.4	302.7	2734.5***
Treatment	20	41063.9***	231.1***	12366.7***	6440.3***
Error	40	129.1	4.1	408.8	322.4
		48 days after application of treatment			
Block	2	426.1	113.9	0.4	420.1
Treatment	20	9754.6***	843.3***	16203.4***	3704.6***
Error	40	477.8	51.9	95.5	203.3
		80 days after application of treatment^			
Block	2		82.4	8576.5***	20.6
Treatment	20		474.8***	19704.8***	2785.6***
Error	40		81.0	908.4	126.3
		111 days after application of treatment			
Block	2	1256.6	25.4	234.1	217.4
Treatment	20	6367.2***	312.4***	2004.5***	1216.3***
Error	40	577.1	53.1	54.4	114.7

^At 80 days Ca concentration was not determined.
***F value significant at 0.1% level.

Table A-18. Significant contrast mean square for Ca, Mg, K, and Cl concentration in water at four dates after application of treatments. Tomato experiment, 1983.

		Ca				Mg				K				Cl			
		Days after application of treatments															
Contrast‡	df	19	48	80$^+$	111	19	48	80	111	19	48	80	111	19	48	80	111
		Mean square															
		Inorganic amendment															
FO-L	1	***	***			***				***	***	**		***	***	***	***
FO-Q	1	*	***			***				***	*			**		**	
BC-R	1					***		***			***		***				*
BC-FL	1		***			***	***			***	***	**	***	***	***	***	*
BC-FQ	1																
BC-RxFL	1					***											
BC-RxFQ	1	***				*											
		Organic amendment															
SS-R	1		***		***		***	**	*		***			**	*	**	
SS-FL	1		***				***		*	***	***	***	**	***	***	***	***
SS-FQ	1						*		**								
SS-RxFL	1		***		***	***	**		**				***				
SS-RxFQ	1				***			**		*	***						
PM-R	1		**		**	**	***		**	***	***	***	***	***	***	***	***
PM-FL	1		***		***		***		*	***	***	***	***	***	***	***	***
PM-FQ	1		***		**						***				*	***	
PM-RxFL	1										***		***				
PM-RxFQ	1		***							*	***	***		*	***	***	
		Amendment comparisons															
FO vs BC	1		**		*			**		***			*			*	
SS vs PM	1	*			***		***	***	***	***	***	***	***	***	***	***	***
OA vs IA	1	***	***		***	***	***	***	***		***	***	***		*	***	***

$^+$Values for Ca concentration at 80 days were not determined.

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

‡See Table 2 in Material and Methods for abbreviations.

Table A-19. Analysis of variance for the effect of 21 treatments on macronutrient concentrations in Mehlich I soil extract at four dates after application of treatments. Tomato experiment, 1983.

Source of variation	df	Mehlich I extract			
		Ca	Mg	K	P
		---------------------- Mean square	-------------		
		19 days after application of treatment			
Block	2	274105	573	321	50417***
Treatment	20	8014778***	8291***	60607***	10189
Error	40	86402	721	3487	
		48 days after application of treatment			
Block	2	23829	309	1126	18151***
Treatment	20	501234***	11588***	56896***	6266***
Error	40	48005	919	2984	1940
		80 days after application of treatment			
Block	2	254970**	609	1036	62064***
Treatment	20	603766***	10328***	27428***	8779
Error	40	45687	818	6614	2714
		111 days after application of treatment			
Block	2	371813***	761	6126	14065*
Treatment	20	296370***	7153***	14609	7163**
Error	40	43374	1774	1147	2788

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

Table A-20. Significant contrast mean square for macronutrients concentrations in Mehlich I soil extract at four dates after application of treatments. Tomato experiment, 1983.

Contrast+	df	Ca				Mg				K				P			
		Days after application of treatments															
		19	48	80	111	19	48	80	111	19	48	80	111	19	48	80	111
		Mean square															
		Inorganic amendment															
FO-L	1		***	***						***						*	
FO-Q	1		**							***			***				**
BC-R	1	**	***	**		***	***	*		*			*			*	
BC-FL	1									*	*		**				
BC-FQ	1	*	***				*	*									
BC-RxFL	1																
BC-RxFQ	1																
		Organic amendment															
SS-R	1	*	***	***	**	***	***	***	***								
SS-FL	1										*	*	*		*		
SS-FQ	1																
SS-RxFL	1					**		**							*		
SS-RxFQ	1						***				*						
PM-R	1	***			***	***	*		*	***	***	*	***			*	
PM-FL	1									***	***	*	***			*	*
PM-FQ	1	***		*	*	**											
PM-RxFL	1	***			*		***			**	***		*				
PM-RxFQ	1	***					*			***							
		Amendment comparisons															
FO vs BC	1		*					*		*					**		
SS vs PM	1	***	**	***	***	*	***	***		***	***	***	***		**	**	
OA vs IA	1	***	**	***	***	***	***	***	***	***	***	***	***			*	

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.
+See Table 2 in Material and Methods for abbreviations.

Table A-21. Significant contrast mean square for Cd, Ni, Mn, Fe and Zn concentration in Mehlich I extract at four dates after application of treatments. Tomato experiment, 1983.

		Cd				Ni				Mn				Fe				Zn			
		Days after application of treatments																			
Contrast+	df	19	48	80	111	19	48	80	111	19	48	80	111	19	48	80	111	19	48	80	111
		Mean square																			
		Inorganic amendment																			
FO-L	1													**	*		*	*	***		***
FO-Q	1														*	*			*	*	
BC-R	1											*									
BC-FL	1												**								
BC-FQ	1												*								
BC-RxFL	1																				
BC-RxFQ	1																				
		Organic amendment																			
SS-R	1	***	***	***	***	***	***	***	***	**	***	***	***		**	**		***	***	***	
SS-FL	1	***	***	***	***	***	***				**						*		***	***	
SS-FQ	1					*		*		*						*					***
SS-RxFL	1		**					***		**	***				***	***	*		*		
SS-RxFQ	1		***	***	***	*					*					*	**			**	*
PM-R	1											*	***	*							
PM-FL	1												**	**							
PM-FQ	1									*											
PM-RxFL	1									*	***										
PM-RxFQ	1									*	*										
		Amendment comparisons																			
FO vs BC	1						*						***					***	***	***	***
SS vs PM	1	***	***	***	***	***	***	***	***									***	***	***	***
OA vs IA	1	***	***	***	***	***	***	***	***	***		**	***					***	***	***	***

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

+See Table 20 in Material and Methods for abbreviations.

Table A-22. Analysis of variance for the effect of 21 treatments on macronutrient concentrations of tomato leaf at three dates after transplant. Tomato experiment, 1983.

Source of variation	df	N			K			Mg		
		41	63	93	41	63	93	41	63	93
		Mean square								
Block	2	3.1	3.0	10.7	10.3	47.1*	39.2*	4.5	1.3**	2.5**
Treatment	20	7.4**	34.5***	77.7***	6.8	40.1***	105.3***	5.2**	1.1***	3.8***
Error	40	3.0	3.4	4.8	6.3	8.3	11.3	1.8	0.2	0.4
Contrast[+]						Inorganic amendment				
FO-L	1	*	***		*					
FO-Q	1	*								
BC-R	1			*		*	*			
BC-FL	1	*	***	***	*	*		*		
BC-FQ	1							***		
BC-RxFL	1									
BC-RxFQ	1									
						Organic amendment				
SS-R	1		***	***						***
SS-FL	1		***				**	**	**	**
SS-FQ	1					*				
SS-RxFL	1							**		
SS-RxFQ	1									
PM-R	1		*	***			***			
PM-FL	1	*	***				**			
PM-FQ	1									
PM-RxFL	1									
PM-RxFQ	1									
						Amendment comparisons				
FO vs BC	1									
SS vs PM	1		***	***	***		***	***		
OA vs IA	1	***	***	***			***	***		

Analysis of variance for P and Ca indicated no significant differences for treatments.

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

[+]See Table 2 in Material and Methods for abbreviations.

Table A-23. Analysis of variance for the effect of 21 treatments on micronutrients and Cd on leaf analysis at three dates after transplant. Tomato experiment, 1983.

Source of variation	df	Cd	Mn	Fe	Zn	Cu
		Mean square				
			41 days after application of treatment			
Block	2	5.0	624.5**	141.7	163.6*	0.03
Treatment	20	18.2***	472.6***	1623.7***	549.9***	0.27***
Error	40	1.2	90.2	188.1	50.2	0.01
			63 days after application of treatment			
Block	2	0.22	814.9	572.0*	64.3	0.042*
Treatment	20	3.80***	891.4*	119.7	364.4***	0.16***
Error	40	0.13	448.3	98.8	41.7	0.009
			93 days after application of treatment			
Block	2	1.10	507.8	132.2	41.4	0.02
Treatment	20	16.26***	7040.2***	965.6***	128.4*	0.18***
Error	40	0.46	1263.5	253.1	59.6	0.02

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

Table A-24. Significant contrast mean square for micronutrients and Cd concentration in leaf at four dates after transplant. Tomato experiment, 1983.

		Cd			Mn			Fe			Zn			Cu		
		Days after application of treatments														
Contrast[+]	df	41	63	93	41	63	93	41	63	93	41	63	93	41	63	93
		Mean square														
		Inorganic amendment														
FO-L	1				***							**	*	*		*
FO-Q	1				***											
BC-R	1				*		*	***		**		*	**			
BC-FL	1							***		***	***	*				
BC-FQ	1															
BC-RxFL	1															
BC-RxFQ	1															
		Organic amendment														
SS-R	1	*	***	***			***	***					***	***		***
SS-FL	1	*	***	***	***		***				**			***		
SS-FQ	1							*			*			**		
SS-RxFL	1				***											***
SS-RxFQ	1						*							**		
PM-R	1				*											
PM-FL	1				***		**				**					
PM-FQ	1															
PM-RxFL	1							***		**						
PM-RxFQ	1					**		***								
		Amendment comparisons														
FO vs BC	1							***		**	*	**				
SS vs PM	1	***	***	***	***	***	*			**	***	***		***	***	***
OA vs IA	1	***	***	***	*	*					***	***		***	***	***

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*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

[+] See Table 2 in Material and Methods for abbreviations.

Table A-25. Analysis of variance for the effect of amendment sources, amendment rate and fertilizer level on macro- and micronutrient concentrations of tomato fruit at 91 days after transplant. Tomato experiment, 1983.

Source of variation	df	N	P	K	Mg	Mn	Cu	Cd
		-------------	-------------	-------------	Mean square	-------------	-------------	-------------
Block	2	12.0	0.65	12.6	0.05	8.05	0.390***	25.3
Treatment	10	12.1**	4.22***	59.1	0.05**	7.63**	0.051**	353.2***
Error	40	4.6	0.39	27.8	0.02	2.65	0.021	10.9
Contrast[+]					Inorganic amendment			
FO-L	1	*						
FO-Q	1							
BC-R	1							
BC-FL	1	*						
BC-FQ	1							
BC-RxFL	1			*		*		
BC-RxFQ	1							
					Organic amendment			
SS-R	1				**			***
SS-FL	1	*	*	*		**		***
SS-FQ	1				**			
SS-RxFL	1							
SS-RxFQ	1		*	**				
PM-R	1	*		*		***	*	
PM-FL	1							
PM-FQ	1							
PM-RxFL	1							
PM-RxFQ	1							
					Amendment comparisons			
FO vs BC	1		***					
SS vs PM	1			**	*		*	***
OA vs IA	1	***	***		*	*	***	***

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

[+] See Table 1 in Material and Methods for abbreviations.

Table A-26. Analysis of variance for the residual effect of the 21 treatments with and without NK application on average fruit weight and fruit yield of cucumber. Cucumber experiment, 1983.

Source of variation	df	Average fruit weight		Fruit yield	
		Early	Final	Early	Final
		---------------- Mean square	----------------	----------------	----------------
Block	2	5462.9***	3481.9***	58.9*	167.9**
Treatment (T)	20	2373.9*	787.4*	66.1***	165.1***
Erro(a)	40	1023.1	381.0	13.2	28.2
NK	1	55.6	221.6	62.0*	124.2**
NK x T	20	757.9	346.4	7.5	8.8
Erro(b)	42	451.1	245.3	5.1	9.9
Contrast+			Inorganic amendment		
FO-L	1	1749.3	159.3	54.8**	63.2*
FO-Q	1	765.6	349.9	0.0	24.2
BC-R	1	1703.7	61.0	19.9	156.8***
BC-FL	1	7.3	102.7	0.6	4.6
BC-FQ	1	1010.3	238.2	45.3**	54.1*
BC-RxFL	1	3140.3*	457.1	15.1	53.1*
BC-RxFQ	1	6.9	213.1	31.9	42.4*
			Organic amendment		
SS-R	1	2075.3*	638.1	44.1**	213.2***
SS-FL	1	319.9	902.2	214.2***	325.8***
SS-FQ	1	870.3	189.2	114.3***	219.4***
SS-RxFL	1	773.3	22.2	4.7	7.7
SS-RxFQ	1	257.7	622.5	0.9	13.9
PM-R	1	0.2	675.9	91.9***	523.1***
PM-FL	1	111.2	2.3	94.9***	319.7***
PM-FQ	1	3731.8**	341.2	14.7	5.1
PM-RxFL	1	0.0	95.1	137.5***	3.1
PM-RxFQ	1	23.7	129.3	0.0	45.3
			Amendment comparison		
FO vs BC	1	17.2	0.2	24.9***	21.4***
SS vs PM	1	18290.9***	8886.3***	38.8***	56.7***
OA vs IA	1	12014.5***	1543.2***	33.0***	58.9***

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.
+See Table 2 in Material and Methods for contrast abbreviations.

Table A-27. Analysis of variance for the residual effect of 21 treatments on soil N, K and EC at three days after cucumber seeding. Cucumber experiment, 1983.

		Soil N extracted					Soil K extracted		
		Water extract		KCl extract	Mehlich I	Available			
	df	NO_3^--N	NH_4^+-N	NH_4^+-N	NH_4^+-N	total N	Water	Mehlich I	EC
		----------	----------	----------	----------	Mean square	----------	----------	----------
Block	2	156.1	0.002	0.114	0.036	164.4	30.5	705.3	0.016
Treatment	20	2319.2***	0.089***	0.356**	0.517**	2306.6***	947.5***	10166.5***	0.160***
Error	40	56.4	0.021	0.144	0.200	56.6	319.3	319.3	0.020
Contrast+						Inorganic amendment			
FO-L	1	***				***	*	***	***
FO-Q	1		***					***	
BC-R	1							***	
BC-FL	1	*				*		***	
BC-FQ	1		*	**					
BC-RxFL	1			**	*			***	
BC-RxFQ	1							*	
						Organic amendment			
SS-R	1	***			**	***			**
SS-FL	1	***	**	*		***			
SS-FQ	1	***	**			***			
SS-RxFL	1	*				*			
SS-RxFQ	1	**				***			
PM-R	1	***		*	**	***	***	***	***
PM-FL	1	***	***			***	***	***	***
PM-FQ	1	*	*			*	***	***	
PM-RxFL	1	***				***	***	*	
PM-RxFQ	1		**				***		
						Amendment comparisons			
FO vs BC	1	*				*	***	***	*
SS vs PM	1				*		***	***	
OA vs IA	1	***				***	***	**	***

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

+See Table 2 in Material and Methods for abbreviations.

Table A-28. Effect of 21 residual treatments on mean soil nutrients in water and Mehlich I extract at three days after cucumber seeding. Cucumber experiment, 1983.

Amendment[+]		Fert.	Water extract			Mehlich I extract		
Source	Rate	level	Ca	Mg	Cl	Ca	Mg	P
			------------------ $mg.kg^{-1}$ ------------------					
					Inorganic amendment			
FO		1400	27	11	27	2166	234	204
		2800	31	10	16	1568	182	345
		4200	35	17	36	1740	160	275
BC		1400	49	16	60	1440	137	282
		2800	50	10	14	1502	139	289
		4200	85	20	59	1777	182	230
BC		1400	47	13	27	2055	227	197
		2800	48	13	16	1650	199	173
		4200	43	10	40	2096	191	243
					Organic amendment			
SS		0	35	14	18	1496	187	277
		1400	51	15	17	1312	180	234
		2800	41	17	18	1305	214	259
SS		0	87	41	25	2245	380	175
		1400	101	35	42	1887	319	287
		2800	128	20	33	1667	297	270
PM		0	47	14	13	2137	195	278
		1400	78	17	35	2133	189	313
		2800	55	13	31	1366	207	226
PM		0	41	10	19	2186	245	335
		1400	46	11	32	1725	202	252
		2800	135	27	30	2242	184	281

[+] See Table 20 for abbreviations.

Table A-29. Means for the main residual effect of 21 treatments on leaf macronutrient concentration at two dates after cucumber seeding. Cucumber experiment, 1983.

Amendment[+]		Fert.	Leaf					
Source	Rate	level	Ca	Mg	P	Ca	Mg	P
	Mg.ha^{-1}	kg.ha^{-1}	g.kg^{-1}					
			22 days[^]			47 days[^]		
FO		1400	25.3	12.2	3.6	22.5	8.2	2.9
		2800	23.6	11.3	3.5	23.4	7.0	2.8
		4200	26.1	9.5	3.6	18.2	5.7	2.6
BC	1.12	1400	21.6	9.3	3.5	15.5	6.7	1.6
	1.12	2800	22.1	8.3	3.7	18.6	6.6	2.2
	1.12	4200	21.8	8.6	3.6	19.4	6.7	2.6
BC	2.24	1400	17.4	8.8	3.1	15.7	7.3	2.3
	2.24	2800	18.7	8.0	3.7	18.3	7.3	2.6
	2.24	4200	17.1	7.6	3.8	19.6	7.1	2.8
SS	11.2	0	17.9	17.4	3.5	26.5	14.7	2.8
	11.2	1400	17.2	14.5	4.0	25.7	12.5	3.1
	11.2	2800	21.7	18.2	3.9	21.9	15.1	3.1
SS	22.4	0	24.5	13.7	3.5	17.7	13.1	2.5
	22.4	1400	23.4	13.1	3.7	22.2	15.9	2.6
	22.4	2800	26.5	15.1	3.7	27.6	16.2	2.6
PM	11.2	0	23.8	11.5	3.3	19.6	8.1	3.4
	11.2	1400	24.4	11.6	3.6	21.6	9.1	2.5
	11.2	2800	25.4	9.1	3.4	26.9	7.0	3.0
PM	22.4	0	19.7	9.2	3.1	21.2	7.9	3.0
	22.4	1400	15.3	7.8	3.9	18.1	7.0	2.9
	22.4	2800	23.1	9.9	3.6	17.6	7.2	3.2

[^] Days after seeding.

[+] See Table 20 for abbreviations.

Table A-30. Means for the main residual effect of 21 treatments on leaf micronutrient concentrations at two dates after cucumber seeding. Cucumber experiment, 1983.

Amendment[+]										
Source	Rate	Fert. level	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
	Mg.ha^{-1}	kg.ha^{-1}	mg.kg^{-1}							
			22 days[^]				47 days[^]			
FO		1400	160	59	60	7.0	116	119	37	5.2
		2800	182	55	53	5.4	158	203	45	3.8
		4200	197	70	66	6.0	146	197	54	3.8
BC	1.12	1400	163	48	41	6.1	160	220	38	3.9
	1.12	2800	209	66	36	5.2	165	239	35	3.2
	1.12	4200	168	73	50	5.6	145	237	40	3.6
BC	2.24	1400	239	48	69	5.7	134	202	39	4.0
	2.24	2800	186	55	56	5.4	176	194	39	3.4
	2.24	4200	192	46	48	5.8	189	233	43	5.5
SS	11.2	0	232	138	48	8.2	200	260	51	5.5
	11.2	1400	267	172	61	8.4	170	268	56	6.3
	11.2	2800	311	152	75	8.7	228	327	71	6.0
SS	22.4	0	220	117	48	7.4	145	173	63	5.6
	22.4	1400	253	170	51	7.5	185	277	57	5.4
	22.4	2800	265	149	60	7.7	186	271	66	5.5
PM	11.2	0	188	55	37	6.9	154	201	48	4.7
	11.2	1400	252	57	46	6.7	115	185	33	4.6
	11.2	2800	237	62	53	7.3	143	225	39	5.4
PM	22.4	0	216	82	41	6.9	228	169	38	5.5
	22.4	1400	191	89	48	6.6	226	190	49	6.4
	22.4	2800	226	109	41	7.7	170	197	44	6.4

[^] Days after seeding.

[+] See Table 20 for abbreviations.

Table A-31. Analysis of variance for the residual effect of 21 treatments with or without NK application on N and K concentration of leaf at two dates after cucumber seeding. Cucumber experiment, 1982.

Source of variation	df	Leaf			
		N	K	N	K
		Mean square			
		22 days^		47 days^	
Block	2	10.9	124.3***	12.4***	258.4*
Treatment (T)	20	35.4*	52.3***	91.3***	294.9***
Erro(a)	40	10.4	9.5	11.5	60.1
NK	1	318.5*	477.4***	0.3	297.9**
NKxT	20	15.1	249.7	11.9	25.1
Erro(b)	42	16.2	13.5	6.2	37.9
Contrast+					
		Inorganic amendment			
FO-L	1		**		
FO-FQ	1				
BC-R	1	**	**		***
BC-FL	1			**	
BC-FQ	1				
BC-RxFL	1				
BC-RxFQ	1				
		Organic amendment			
SS-R	1	***		**	***
SS-FL	1		**		**
SS-FQ	1				*
SS-RxFL	1	**		*	
SS-RxFQ	1				***
PM-R	1		***	***	
PM-FL	1	***	***		
PM-FQ	1				
PM-RxFL	1	**	*	**	
PM-RxFQ	1				
		Amendment comparisons			
FO vs BC	1				
SS vs PM	1	***	***	***	***
OA vs IA	1			***	**

^Days after seeding.

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.

+See Table 2 in Material and Methods for abbreviations.

Table A-32. Means for the main residual effect of 21 treatments on fruit macro- and micronutrients concentrations. Cucumber experiment, 1983.

Amendment+		Fert.	Fruit						
Source	Rate	level	Ca	Mg	P	Fe	Mn	Zn	Cu
	$Mg.ha^{-1}$	$kg.ha^{-1}$	---------- $g.kg^{-1}$ ---------			---------------- $mg.kg^{-1}$ --------------			
					Inorganic amendment				
FO		1400	2.3	2.9	5.8	43	22	37	8.2
		2800	2.3	2.7	5.3	39	24	40	8.9
		4200	2.3	2.8	5.6	43	10	41	8.8
BC		1400	2.7	2.9	5.8	50	12	42	7.5
		2800	2.3	2.5	4.4	42	11	35	8.0
		4200	2.4	2.6	5.0	45	10	38	6.7
BC		1400	2.2	3.2	5.9	41	10	44	6.9
		2800	2.1	3.2	6.1	39	12	44	7.8
		4200	2.8	3.2	5.1	45	14	43	7.6
SS		0	2.3	3.0	5.6	42	12	45	7.9
		1400	2.4	3.0	5.3	54	12	48	8.1
		2800	2.5	3.3	5.3	51	13	49	7.6
SS		0	2.8	3.3	5.7	54	13	52	9.1
		1400	2.7	3.5	5.2	58	14	43	7.6
		2800	3.0	3.7	5.2	55	18	46	7.2
PM		0	2.6	3.2	5.3	50	14	44	6.7
		1400	2.5	3.0	5.5	46	11	39	7.8
		2800	2.7	2.9	5.6	49	12	41	7.5
PM		0	2.6	2.9	5.1	39	11	46	6.4
		1400	2.5	2.9	5.7	47	15	42	7.6
		2800	2.8	3.0	5.7	47	12	35	7.5

+See Table 20 for abbreviations.

Table A-33. Analysis of variance for the residual effect on fruit N and K of 21 treatments with or without application of N and K. Cucumber experiment, 1983.

Source of variation	df	Fruit			
		N		K	
		Mean square			
Block	2	4.0		8.4	
Treatment (T)	20	205.2***		102.9***	
Erro(a)	40	5.4		24.8	
NK	1	5.7		1.9	
NKxT	20	13.1**		56.7*	
Erro(b)	42	4.9		28.0	
Contrast⁺		-NK	+NK	-NK	+NK
		Inorganic amendment			
FO-L	1			*	
FO-FQ	1				
BC-R	1	*		*	***
BC-FL	1		*		**
BC-FQ	1				***
BC-RxFL	1				
BC-RxFQ	1				
		Organic amendment			
SS-R	1	***	***		*
SS-FL	1	**			***
SS-FQ	1				
SS-RxFL	1		***		
SS-RxFQ	1				
PM-R	1				***
PM-FL	1				
PM-FQ	1	*			
PM-RxFL	1				
PM-RxFQ	1				
		Amendment comparisons			
FO vs BC	1	*	*		***
SS vs PM	1	***	*	**	**
OA vs IA	1	***	***		*

*, **, ***F value significant at the 5%, 1% and 0.1% levels, respectively.
⁺See Table 2 in Material and Methods for abbreviations.

LITERATURE CITED

Adriano, D.C., P.F. Pratt, and S.E. Bishop. 1971. Nitrate and salt in soils and ground waters from land disposal of dairy manure. Soil Sci. Soc. Amer. Proc. 35:759-762.

Aggarwal, R.K., J.P. Gupta, and P. Kaul. 1980. Nitrogen mineralization as affected by the addition of pond sediments and bentonite clay to a sandy soil under different moisture regimes. J. Indian Soc. Soil Sci. 28(4):444-449.

Albregts, E.E. 1971. Effect of nitrogen and potassium on bell pepper grown under paper mulch. Soil Crop Sci. Soc. Fla. Proc. 31:116-118.

Albregts, E.E., and C.M. Howard. 1981. Effect of poultry manure on strawberry fruiting responses, soil nutrient changes, and leaching. J. Amer. Soc. Hort. Sci. 106(3):295-298.

Allaway, W.H. 1968. Agronomic control over environmental cycling of trace elements. Advan. Agron. 20:235-274.

Allen, A.L., F.J. Stevenson, and L.T. Kurtz. 1973. Chemical distribution of residual fertilizer nitrogen in soil as revealed by nitrogen-15 studies. J. Environ. Qual. 2:120-124.

Allison, F.E. 1964. The soil nitrogen balance--A continuing enigma. p. 1-13. In Nitrogen Research, A Symposium. Tennessee Valley Authority, Wilson Dam, Ala.

Allison, F.E. 1965. Organic carbon. p. 1367-1378. In C.A. Black (ed.). Methods of Soil Analysis. Part 2. Amer. Soc. Agron., Inc., Madison, Wisc.

Allison, F.E. 1973a. Maintenance of soil organic matter. p. 417-444. In Soil Organic Matter and Role in Crop Production. Elselvier Scientific Publishing Company, Inc., Amsterdam, Netherlands.

Allison, F.E. 1973b. The use of peat for crop production. p. 603-617. In Soil Organic Matter and Role in Crop Production. Elselvier Scientific Publishing Company, Inc., Amsterdam, Netherlands.

Baker, D.E., R.M. Eshelman, and R.M. Leach. 1975. Cadmium in sludge potentially harmful when applied to crops. Sci. Agric. 22:14-15.

Berrow, J.L., and J. Webber. 1972. Trace elements in sewage sludges. J. Sci. Food Agric. 23:93-100.

Bielby, D.G., M.H. Miller, and L.R. Webber. 1973. Nitrate content of percolates from manure lysimeters. J. Soil Water Conserv. 28:124-126.

Bingham, F.T., A.L. Page, G.A. Mitchell, and J.E. Strong. 1979. Effects of liming an acid soil amended with sewage sludge enriched with Cd, Cu, Ni and Zn on yield and Cd content of wheat grain. J. Environ. Qual. 8:202-206.

Black, C.A. 1968. Salinity and excess sodium. p. 356-505. In Soil-Plant Relationships. John Wiley & Sons, Inc., New York.

Bohn, H.L., McNeal, B.L., and O'Connor, G.A. 1979. Salt-affected soils. p. 217-246. In Soil Chemistry. Wiley-Interscience Publ., New York.

Bremner, J.M. 1965. Inorganic forms of nitrogen. p. 1179-1237. In C.A. Black (ed.). Methods of Soil Analysis. Part 2. Amer. Soc. Agron., Inc., Madison, Wisc.

Broadbent, F.E. 1980. Residual effects of labeled N in field trials. Agron. J. 72:325-329.

Broadbent, F.E. 1981. Methodology for nitrogen transformation and balance in soil. Plant and Soil 58:383-399.

Broadbent, F.E., and A.B. Carlton. 1978. Field trials with isotopically labeled nitrogen fertilizer. In D.R. Nielsen and J.G. MacDonald (eds.). Nitrogen in the Environment. 1:1-41.

Broadbent, F.E., and T. Nakashima. 1967. Revision of fertilizer nitrogen in soils. Soil. Sci. Soc. Am. Proc. 31:648-652.

Broadbent, F.E., K.B. Tyler, and D.M. May. 1980. Tomatoes make efficient use of applied nitrogen. Calif. Agric. 34:24-25.

Bryan, H.H., and J.D. Dalton. 1974. Yield responses of tomatoes and second cropped butternut squash to fertilizer rate and placement under plastic mulch on Rockdale soil. Proc. Fla. State Hort. Soc. 87:159-164.

Buresh, R.J., E.R. Austin, and E.T. Craswell. 1982. Analytical methods in ^{15}N research. Fertilizer Research 3:37-62.

Burl, M., L. Graham, and D. Terry. 1982. Long-term effects of manure on soil nitrogen, phosphorus, potassium, sodium, organic matter, and water infiltration rate. Soil. Sci. Soc. Am. J. 46:1014-1019.

Caddy, F.B., and W.U. Bartholomew. 1960. Greenhouse recovery of added tracer nitrogen. Soil Sci. Soc. N. Car. 3:44-54.

Carlisle, W.V., C.T. Hallmark, F. Sodek, R.E. Caldwell, L.C. Hammond, and V.E. Berkheiser. 1981. Characterization data for selected Florida soils. 1982. USDA, Soil Conservation Service and Soil Science Dept., Univ. Florida, Gainesville, Fla.

Carlson, C.W., and J.D. Menzies. 1971. Utilization of urban wastes in crop production. BioScience 21:561-564.

Castellanos, J.Z., and P.F. Pratt. 1981. Mineralization of manure nitrogen-correlation with laboratory indexes. Soil Sci. Soc. Am. J. 45:354-357.

Cebula, J. 1982. Applicability of municipal sludges for agricultural utilization. Agricultural Wastes 4:173-191.

Chaney, R.L. 1980. Health risks associated with toxic metals in municipal sludge. p. 59-63. In G. Bitton, B.L.G.T. Damon, G.T. Edds, J.M. Davidson (eds.). Sludge-Health Risks of Land Application. Ann Arbor Sci. Pub., Ann Arbor, Mich.

Chaney, R.L., and P.M. Giordano. 1977. Microelements as related to plant deficiencies and toxicities. p. 233-280. In L.F. Elliot and F.J. Stevenson (eds.). Soils For Management and Utilization of Organic Wastes and Waste Waters. Amer. Soc. Agron., Inc., Madison, Wisc.

Chapman, H.D. 1966. Diagnostic Criteria For Plants and Soil. Quality Printing Co., Inc., Abilene, Texas.

Chase, F.E., C.T. Corke, and J.B. Robinson. 1968. Nitrifying bacteria in soils. p. 593-611. In T.R.G. Gray and D. Parkinson (eds.). The Ecology of Soil Bacteria. Liverpool University Press, Liverpool.

Cheung, Y.H., and M.H. Wong. 1983. Utilization of animal manures and sewage sludge for growing vegetables. Agricultural Wastes 5(2):63-81.

Chichester, F.W., J.O. Legg, and G. Stanford. 1975. Relative mineralization rates of indigenous and recently incorporated ^{15}N-labelled nitrogen. Soil Sci. 120:455-460.

Coker, E.G. 1966. The value of liquid digested sewage sludge. J. Agric. Sci. 67:99-103.

Collins, J.F., and E. Coyle. 1980. Long-term changes in soil macromorphological properties under the influence of peat debris. J. Soil Sci. 31:547-558.

Cooke, G.W. 1982. Making recommendations and selecting fertilizers. p. 302-308. In Fertilizing For Maximum Yield. Macmillan Publishing Co., Inc., New York.

Cooke, G.W., G.E.C. Mattingly, and R.J.B. Williams. 1958. Changes in soil of a long continued field experiments at Saxmundham, Suffolk. J. Soil Sci. 9:298-305.

Cowan, M.C. 1976. An evaluation of farmyard slurry enriched with poultry manure or inorganic N-P-K as fertilizer for perennial ryegrass. Plant and Soil 45:625-635.

Csizinszky, A.A. 1978. Utilization of residual fertilizers of a fall tomato crop by direct seeded and transplanted vegetables. AREC, Bradenton Research Rpt. GC 1978-1. IFAS, Univ. of Florida, Bradenton, Fla.

Cunningham, J.D., D.R. Keeney, and J.A. Ryan. 1975. Yield and metal composition of corn and rye grown on sewage sludge-amended. Soil J. Environ. Qual. 4:448-454.

Diamond, R.B., and J.G.A. Fiskell. 1965. Amendments of sandy soil with a phosphatic clay. Soil Crop Sci. Soc. Fla. Proc. 25:190-202.

Diez, T. 1982. Increasing organic matter of soils by sewage sludge. p. 2-8. In G. Catroux, P. L'hermite, and E. Suess (eds.). The Influence of Sewage Sludge Application on Physical and Biological Properties of Soil. Commission of the European Communities, Munich, Germany.

Doss, B.D., Z.F. Lund, F.L. Long, and L. Mugwina. 1976. Dairy cattle waste management: Its effect on forage production and runoff water quality. Alabama Agric. Exp. Stn. Bull. 495.

Dowdy, R.H., and W.E. Larson. 1975. The availability of sludge-borne metals to various vegetable crops. J. Environ. Qual. 4:278-282.

Dubetz, S., G.C. Kozub, and J.F. Dorman. 1975. Effects of fertilizer, barnyard manure, and crop residue on irrigated crop yields and soil chemical properties. Can. J. Soil Sci. 55:481-490.

Dyal, R.S. 1960. Physical chemical properties of some peats used as soil amendments. Soil. Sci. Soc. Am. Proc. 24:268-270.

Eno, C.F. 1962. Chicken manure. Fla. Agr. Expt. Cir. S-140. University of Florida, Gainesville.

Environment Protection Agency. 1976. Method for chemical analysis of water and wastes. Environmental Monitoring and Support Laboratory Environ. Res. Center, Cincinnati, Ohio.

EPA. 1980. Hazardous waste and consolidated permit regulations. Federal Register. 45(98):33063-33285.

Epstein, E. 1975. Effects of sewage sludge on some soil physical properties. J. Environ. Qual. 4:139-142.

Epstein, E., D.B. Keane, J.J. Meisinger, and J.O. Legg. 1978. Mineralization of nitrogen from sewage and compost. J. Environ. Qual. 7:217-221.

Epstein, E., J.M. Taylor, and R.L. Chaney. 1976. Effects of sewage sludge and sludge compost applied to soil on some soil physical and chemical properties. J. Environ. Qual. 5:422-426.

Everett, P.H. 1971. Evaluation of paper and polyethylene coated paper mulches and fertilizer rates for tomato. Proc. Fla. State Hort. Soc. 84:124-128.

Everett, P.H. 1976. Effect of nitrogen and potassium rates on fruit yield and size of mulch-grown staked tomatoes. Proc. Fla. State Horst. Soc. 89:159-162.

Everett, P.H. 1978. Fertilizing tomatoes or cucumbers as second crops on plastic mulched beds. Proc. Fla. State Hort. Soc. 91:317-319.

Fiskell, J.G.A., R.B. Diamond, and E.A. Brams. 1967. Effects of soft rock phosphate upon citrus seedling roots and in soil. Soil Crop Sci. Soc. Fla. Proc. 27:313-321.

Fiskell, J.G.A., and S.J. Locascio. 1983. Changes in available N for drip-irrigated tomatoes from preplant and fertigation N sources. Soil Crop Sci. Soc. Fla. Proc. 42:180-184.

Fiskell, J.G.A., S.J. Locascio, P.H. Everett, and H.W. Lundy. 1967. Effect of fertilizer placements and rates on watermelon yields. Proc. Fla. State Hort. Soc. 80:168-173.

Fiskell, J.G.A., S.J. Locascio, S. Singholka, and F.G. Martin. 1977. Effects of fertilizer N sources, rates, and placement on soil test values for bedded peppers with and without mulch. Soil Crop Sci. Soc. Fla. Proc. 37:183-188.

Fiskell, J.G.A., and L.W. Zelazny. 1971. Acidic properties of some Florida soils--pH dependent cation exchange. Soil Crop Sci. Soc. Fla. Proc. 31:145-149.

Foy, C.D., R.L. Chaney, and M.C. White. 1978. The physiology of metal toxicities in plants. Annu. Rev. Plant Physiol. 29:511-566.

Fried, M., and R.E. Shapiro. 1961. Soil-plant relationships in ion uptake. Ann. Rev. Plant Physiol. 12:91-112.

Geraldson, C.M. 1962. Growing tomatoes and cucumbers with high analysis fertilizers and plastic mulch. Proc. Fla. State Hort. Soc. 75:253-260.

Geraldson, C.M. 1963. Quantity and balance of nutrients required for best yields of tomato. Proc. Fla. State Hort. Soc. 76:153-158.

Gill, H.S., and O.P. Meelu. 1982. Studies on the substitution of inorganic fertilizer with organic manure and their effect on soil fertility in rice-wheat rotation. Fertilizer Research 3:303-314.

Giordano, P.M., J.J. Mortvedt, and D.A. Mays. 1975. Effect of municipal wastes on crop yields and uptake of heavy metals. J. Environ. Qual. 4:394-399.

Guenzi, W.D., W.E. Beard, F.S. Watanabe, S.R. Olsen, and L.K. Porter. 1978. Nitrification and denitrification in cattle manure-amended soil. J. Environ. Qual. 7:196-202.

Guidi, G., M. Pagliai, and M. Giachetti. 1981. Modifications of some physical and chemical soil properties following sludge and compost applications. p. 122-130. In G. Catroux, P. L'hermite, and E. Suess. (eds.). The Influence of Sewage Sludge Application on Physical and Biological Properties of Soil. Commission of the European Communities, Munich, Germany.

Guilarte, T.C., R.E. Perez-Levy, and G.M. Prine. 1975. Some double cropping possibilities under irrigation during the warm season in North and West Florida. Soil Crop Sci. Soc. Fla. Proc. 34:138-143.

Gupta, J.P., and P.K. Aggarwal. 1980. Soil physical properties and nitrogen mineralization as affected by bentonite clay and pond sediment amendment. Agrochimica. 24:416-423.

Gupta, S.C., R.H. Dowdy, and W.E. Larson. 1977. Hydraulic and thermal properties of a sandy soil as influenced by incorporation of sewage sludge. Soil Sci. Soc. Am. J. 41(3):601-605.

Hall, J.E., and E.G. Coker. 1981. Some effects of sewage sludge on soil physical conditions and plant growth. p. 43-60. In G. Catroux, P. L'hermite, and E. Suess (eds.). The Influence of Sewage Sludge Application on Physical and Biological Properties of Soil. Commission of the European Communities, Munich, Germany.

Hallenbeck, W.H. 1979. Municipal sludge management: Health aspects of crop uptake of cadmium from sludge-amended soil and recommendations for regulation. Env. Management. 3:155-158.

Hauck, R.D., and J.M. Bremmer. 1976. Use of tracers for soil and fertilizer nitrogen research. Adv. Agron. 28:219-266.

Hayslip, N.C., and J.R. Iley. 1964. Tomato fertility trials on sandy soils. Proc. Fla. State Hort. Soc. 77:168-172.

Helwig, J.T., and J.A. Council (eds). 1979. SAS User's Guide. SAS Institute, Inc., Raleigh, North Carolina.

Hills, F.J., A. Abshahi, F.E. Broadbent, and G.A. Peterson. 1981. Effect of nitrapyrin on uptake of nitrogen by sugarbeet from labeled ammonium sulfate. J. Am. Soc. Sugar Beet Technol. 21:150-158.

Hills, F.J., F.E. Broadbent, and M. Fried. 1978. Timing and rate of fertilizer nitrogen for sugarbeets related to nitrogen uptake and pollution potential. J. Environ. Qual. 7:368-372.

Hills, F.J., F.E. Broadbent, and O.A. Lorenz. 1983. Fertilizer nitrogen utilization by corn, tomato and sugarbeet. Agron. J. 75:423-426.

Hinesly, T.D., R.L. Jones, and E.L. Ziegler. 1972. Effects on corn by applications of heated anaerobically digested sludge. Compost Sci. 13(4):26-30.

Hipp, B.W., and G.W. Thomas. 1968. Method for predicting potassium uptake by grain sorghum. Agron. J. 60:467-469.

Hitz, C.W. 1951. Utilization of chicken manure in the production of strawberries. Proc. Fla. State Hort. Soc. 57:37-44.

Hook,J.E., and L.T. Kardos. 1977. Nitrate relationship in the Penn State "Living Filter" system. p. 181-198. In R.C. Loehr (ed.). Land as a Waste Management Alternative. 1976 Cornell Agric. Waste Management Conf., Ann Arbor Sci. Publ., Ann Arbor, Mich.

Hsieh, Y.P., L.A. Douglas, and H.L. Motto. 1981a. Modeling sewage sludge decomposition in soil. I. Organic carbon transformation. J. Environ. Qual. 10:54-59.

Hsieh, Y.P., L.A. Douglas, and H.L. Motto. 1981b. Modeling sewage sludge decomposition in soil. II. Nitrogen transformation. J. Environ. Qual. 10:59-64.

Institute of Food and Agricultural Science. 1983. Tomato committee report. p. 151-214; Vine crops committee report. p. 219-221. In Vegetable Crops Committee Reports. Florida Agriculture In the 80's. Commodity Committees, University of Florida, Gainesville.

Jackson, W.A., R.A. Leonard, and S.R. Wilkinson. 1975. Land disposal of broiler litter: Changes in soil potassium, calcium and magnesium. J. Environ. Qual. 4:202-206.

Jackson, W.A., S.R. Wilkinson, and R.A. Leornard. 1977. Land disposal of broiler litter: Changes in concentration of cloride, nitrate nitrogen, total nitrogen and organic matter in a Cecil sandy soil. J. Environ. Qual. 6:58-62.

Johnston, A.E., and P.C. Brookes. 1978. Yields of and P, K, Ca, Mg uptake by crops grown in an experiment testing the effects of adding peat to a sandy loam soil at Woburn, 1963-1977. Rothamsted Experimental Station Report for 1977, Part 2, 67-82. Rothasmsted Experimental Station, Harpenden, England.

Jones, R.L., T.D. Hinesly, E.L. Ziegler, and J.J. Tyler. 1975. Cadmium and zinc contents of corn leaf and grain produced by sludge-amended soil. J. Environ. Qual. 4:509-514.

Kardos, L.T., C.E. Scarbrook, and V.V. Volk. 1977. Recycling elements in wastes through soil-plant systems. p. 301-324. In L.F. Elliot and F.J. Stevenson (eds.). Soils For Management of Organic Waste and Waste Waters. Amer. Soc. Agron. Inc., Madison, Wisc.

Keeney, D.R., K.W. Lee, and L.M. Walsh. 1975. Guidelines for the application of wastewater sludge to agricultural land in Wisconsin Tech. Bull. 88. Wisconsin DNR, Madison, Wisc.

Kelling, K.A., A.E. Peterson, L.M. Walsh, J.A. Ryan, and D.R. Keeney. 1977a. A field study of the agricultural use of sewage sludge: I. Effect on crop yield and uptake of N and P. J. Environ. Qual. 6:339-344.

Kelling, K.A., L.M. Walsh, D.R. Keeney, J.A. Ryan, and A.E. Peterson. 1977b. A field study of the agricultural use of sewage sludge: II. Effect on soil N and P. J. Environ. Qual. 6:345-351.

Kimble, J.M., R.J. Bartlett, J.L. McIntosh, and K.E. Varney. 1972. Fate of nitrate from manure and inorganic nitrogen in a clay soil cropped to continuous corn. J. Environ. Qual. 1:413-415.

King, L.D. 1973. Mineralization and gaseous loss of nitrogen in soil applied liquid sewage sludge. J. Environ. Qual. 1:413-415.

King, L.D., and H.D. Morris. 1972. Land disposal of sewage sludge: II. Effect on soil pH, manganese, zinc, and growth and chemical composition of rye. J. Environ. Qual. 3:361-366.

King, L.D., and H.D. Morris. 1974. Nitrogen movement resulting from surface application of liquid sewage sludge. J. Environ. Qual. 3:238-243.

King, K.D., L.A. Rudgers, and L.R. Webber. 1974. Application of municipal refuse and liquid sewage sludge to agricultural land: I. A field study. J. Environ. Qual. 3:361-366.

Kiver, F.V., and F.Ye. Kiver. 1976. Duration of the effect of manure on irrigated dark chestnut soil in the Ukraine. Soviet Soil Science 7:310-313.

Kretschmer, A.E., N.C. Hayslip, and W.T. Forsee. 1963. Spring field corn and sorghum production after fall vegetables. Fla. Agr. Expt. Sta. Cir. 5-145.

Legg, J.O., F.W. Chichester, G. Stanford, and W.H. DeMar. 1971. Incorporation of ^{15}N-tagged mineral nitrogen into stable forms of soil organic nitrogen. Soil Sci. Soc. Am. Proc. 35:273-276.

Lhotsky, J. 1974. A theory of soil improvement by application of sorbents. Transactions, 10th International Congress of Soil Science (Czechoslovakia), IV. 1974:420-426.

Liebhardt, C.W., and J.G. Shortall. 1974. Potassium is responsible for salinity in soils amended with poultry manure. Comm. in Soil Science and Plant Analysis 5:385-398.

Locascio, S.J., and J.G.A. Fiskell. 1977. Pepper production as influenced by mulch, fertilizer placement, and nitrogen rate. Soil Crop Sci. Soc. Fla. Proc. 36:113-117.

Locascio, S.J., and J.G.A. Fiskell. 1979. Pepper response to sulfur-coated urea, mulch and nitrogen rate. Proc. Fla. State Hort. Soc. 92:112-115.

Locascio, S.J., J.G.A. Fiskell, and H.W. Lundy. 1973. Watermelon response to sulfur-coated urea, mulches and nitrogen rates. Proc. Fla. State Hort. Soc. 86:201-204.

Locascio, S.J., J.G.A. Fiskell, and F.G. Martin. 1981. Response of bell pepper to nitrogen sources. J. Amer. Soc. Hort. Sci. 106(5):628-632.

Locascio, S.J., and J.M. Myers. 1974. Tomato response to plug-mix, mulch, and irrigation method. Proc. Fla. State Hort. Soc. 87:126-130.

Locascio, S.J., and J.M. Myers. 1975. Trickle irrigation and fertilization method for strawberries. Proc. Fla. State Hort. Soc. 88:185-189.

Locascio, S.J., J.M. Myers, and J.G.A. Fiskell. 1982. Nitrogen application timing and source for drip irrigated tomatoes. p. 323-328. In A. Scaife (ed.). Proc. 9th Int. Plant Nutr. Colloquim. Vol. 1. Warwick University, England.

Locascio, S.J., and B.D. Thompson. 1960. Strawberry yield and the soil nutrient levels as affected by fertilizer rate, type of mulch and time of application. Proc. Fla. State Hort. Soc. 73:172-179.

Long, F.L., Z.F. Lund, and R.E. Hermanson. 1975. Effect of soil-incorporated dairy cattle manure on runoff water quality and soil properties. J. Environ. Qual. 4:163-166.

Lucka, M., J. Kalon, and W. Sady. 1977. The effect of organic fertilizers on the yield and chemical composition of the strawberry cultivar Purpuratka grown from plants free of nematodes and strawberry mites. Hort. Abst. 48(7):2175.

Lund, Z.F., and B.D. Doss. 1980. Residual effects of dairy cattle manure on plant growth and soil properties. Agron. J. 72:123-130.

MacMillan, K.A., T.W. Scott, and J.W. Bateman. 1975. Corn response and soil nitrogen transformation following varied applications of poultry manure treated to minimize odor. Can. J. Soil Sci. 55:29-34.

Magdoff, F.R., and J.F. Amadon. 1980. Nitrogen availability from sewage sludge. J. Environ. Qual. 9:451-455.

Magdoff, F.R., and F.W. Chromec. 1977. Nitrogen mineralization from sewage sludge. J. Environ. Sci. Health A12:191-201.

Mann, H.H., and T.W. Barnes. 1956. The performance of organic matter added to the soil. J. Agric. Sci. 48:160-163.

Marlowe, G.A., Jr., and J.A. Cornell. 1977. The influence of specific ions on the total soluble salt and pH levels of commercial tomato fields in southwest Florida. Proc. Fla. State Hort. Soc. 90:388-390.

Martin, H.L. 1933. The influence of the chemical composition of organic matter on rate of decomposition. J. Amer. Soc. Agron. 25:341-346.

Mathers, A.C., and B.A. Stewart. 1971. Nitrogen transformations and plant growth as affected by applying large amounts of cattle feedlot waste to soil. p. 207-214. In Relationship of Agriculture to Soil and Water Pollution. Proc. Cornell Agric. Waste Manage. Conf., Rochester, N.Y.

Mathers, A.C., and B.A. Stewart. 1974. Corn silage yield and chemical properties as affected by cattle feedlot manure. J. Environ. Qual. 3:143-147.

Mathers, A.C., B.A. Stewart, J.D. Thomas. 1975. Residual and annual rate effects of manure and grain sorghum yields. p. 252-350. In Conference Proceedings of the 3rd International Symposium on Livestock Wastes. Am. Soc. of Agric. Eng., St. Joseph, Mich.

Mathers, A.C., B.A. Stewart, J.D. Thomas, and B.J. Blair. 1972. Effects of cattle feedlot manure on crop yields and on soil conditions. Texas Agric. Exp. Stn., Res. Center Tech. Rep. no. 11:13.

Maynard, D.N., and S.J. Locascio. 1982. Nutrition of vegetable crops in Florida, USA. Proc. 21st International Horticultural Congress 2:710-725. Hamburg, Germany.

McIlveen, W.D., and H. Cole, Jr. 1977. Influence of sewage sludge soil amendment on various biological components of the corn field ecosytem. Agric. Environm. 3:349-361.

McIntosh, J.L., and K.E. Varney. 1973. Accumulative effects of manure and N on continuous corn and clay soil. II. Chemical changes in soil. Agron. J. 64:374-379.

Meek, B., Graham, L., and Donovan, T. 1982. Long-term effects of manure on soil nitrogen, phosphorus, potassium, sodium, organic matter, and water infiltration rate. Soil Sci. Soc. Am. J. 46:1014-1019.

Meek, B.D., A.M. MacKenzie, T.J. Donovan, and W.F. Spencer. 1974. The effects of large applications of manure on movement of nitrate and carbon in an irrigated desert region. J. Environ. Qual. 3:253-258.

Mengel, K., and E.A. Kirby. 1979. The soil as a plant nutrient medium. In Principles of Plant Nutrition. International Potash Institute, Switzerland.

Micthell, G.A., F.T. Bingham, and A.L. Page. 1978a. Yield and metal composition of lettuce and wheat grown on soils amended with sewage sludge enriched with cadmium, copper, nickel, and zinc. J. Environ. Qual. 7:165-170.

Micthell, M.J., R. Hartenstein, B.L. Swift, E.F. Neuhauser, B.I. Abrams, R.M. Mulligan, B.A. Brown, D. Craig, and D. Kaplan. 1978b. Effects of different sewage sludges on some chemical and biological characteristics of soil. J. Environ. Qual. 7:551-559.

Micthell, M.J., R.M. Mulligan, R. Hartentein, and E.F. Neuhauser. 1977. Conversion of sludges of "topsoils" by earthworms. Comp. Sci. 18(4):28-32.

Miller, R.J., D.E. Rolston, R.S. Rauschkolb, and D.W. Wolfe. 1981. Labeled nitrogen uptake by drip-irrigated tomatoes. Agron. J. 73:265-270.

Milne, R.A., and D.N. Graveland. 1972. Sewage sludge as a fertilizer. Can. J. Soil Sci. 52:270-273.

Morelock, T.E., and M.R. Hall. 1980. Use of broiler litter on staked tomato. Arkansas Farm Research 29(1):10.

Munro, D.C., D.C. MacKay, and J.A. Cutcliffe. 1978. Relation of nutrient content of broccoli and brussels sprouts leaves to maturity and fertilization with N, P, K and manure. Can. J. Plant Sci. 58:385-394.

Navarro, A.A., and S.J. Locascio. 1971. Influence of population density, row spacing and fertilizer rate on the single harvest yield of fresh market tomatoes. Proc. Fla. State Hort. Soc. 76:185-191.

Navarro, A.A., and S.J. Locascio. 1973. Cucumber response to copper rate and fertilizer placement. Proc. Fla. State Hort. Soc. 78:193-195.

Nelson, D.W., and L.E. Sommers. 1973. Determination of total nitrogen in plant material. Agron. J. 65:109-112.

Norman, A.G., and C.H. Werkman. 1943. The use of ^{15}N in determining N recovery from plant materials decomposing in soil. J. Am. Soc. Agron. 35:1023-1025.

Olsen, R.V. 1980. Fate of tagged nitrogen fertilizer applied to irrigated corn. Soil Sci. Soc. Am. J. 44:514-517.

Olsen, P.J., R.F. Hensler, and O.J. Attoe. 1970. Effect of manure application, aeration, and soil pH on soil nitrogen transformations and on certain soil test values. Soil Sci. Soc. Am. Proc. 34:222-225.

Page, A.L., F.T. Bingham, and C. Nelson. 1972. Cadmium adsorption and growth of various plant species as influenced by solution cadmium concentration. J. Environ. Qual. 1:228-291.

Parr, J.F., and G.B. Willson. 1980. Recycling organic wastes to improve soil productivity. Hort. Science 15(2):162-166.

Persuad, N., S.J. Locascio, and C.M. Geraldson. 1976. Effect of rate and placement of nitrogen and potassium on yield of mulched tomato using different irrigation methods. Proc. Fla. State Hort. Soc. 89:135-138.

Pomares-Garcia, F., and P.F. Pratt. 1978. Recovery of ^{15}N-labeled fertilizer from manure and sludge-amended soil. Soil Sci. Soc. Am. J. 42:717-720.

Pratt, P.E., F.E. Broadbent, and J.P. Martin. 1973. Using organic wastes as nitrogen fertilizers. Calif. Agric. 27(6):10-13.

Pratt, P.F., S. Davis, and R.G. Sharpless. 1976. A four-year field trial with animal manures. I. Nitrogen balances and yields. II. Mineralization of nitrogen. Hilgardia 44:99-125.

Pratt, P.F., and A.L. Page. 1976. Leachate from applications of fertilizers manures, and sewage sludge to land. p. 59-68. In Disposal of Residues On Land. Proceeding of the National Conference on Disposal of Residues on Land, St. Louis, Missouri.

Premi, P.R., and A.H. Cornfield. 1969. Incubation study of nitrification of digested sewage sludge added to soil. Soil Biol. Biochem. 1:1-4.

Premi, P.R., and A.H. Cornfield. 1971. Incubation study of nitrogen mineralization in soil treated with dried sewage sludge. Environ. Pollut. 2:1-5.

Reddy, K.R., R. Khaleef, and M.R. Overcash. 1980. Nitrogen, phosphorus and carbon transformation in a coastal plain soil treated with animal manures. Agricultural Wastes 2:225-238.

Ridley, A.O., and R.A. Hedlin. 1968. Soil organic matter and crop yields as influenced by the frequency of summer fallowing. Can. J. Soil Sci. 48:315-322.

Rolston, D.E. 1978. Application of gaseous diffusion theory to measurement of denitrification. p. 309-335. In D.R. Nielsen and J.G. MacDonald (eds.). Nitrogen In the Environment. Vol. 1: Nitrogen Behavior in Field Soil. Academic Press, Inc., New York.

Rolston, D.E., F.E. Broadbent, and D.A. Goldhamer. 1979. Field measurement of denitrification. II. Mass balance and sampling uncertainty. Soil Sci. Soc. Am. J. 40:259-266.

Rothwell, D.F., and C.C. Hortenstine. 1969. Compost municipal refuse: Its effects on carbon dioxide, nitrate, fungi, and bacteria in Arredondo fine sand. Agron. J. 61:837-840.

Ryan, J.A., D.R. Keeney, and L.M. Walsh. 1973. Nitrogen transformation and availability of an anaerobically digested sewage sludge in soil. J. Environ. Qual. 2:489-492.

Sabey, B.R., and W.E. Hart. 1975. Land application of sewage sludge: I. Effect on growth and chemical composition of plants. J. Environ. Qual. 4:252-256.

Salter, P.J., J.B. Williams, and D.J. Harrison. 1965. Effects of bulk organic manures on the available water capacity of a fine sandy loam. Experimental Horticulture 13:69-75.

Sarathchandra, S.V. 1978. Nitrification activities and the changes in the populations of nitrifying bacteria in soil perfused at two different H-ion concentrations. Plant and Soil 50:99-111.

Schalscha, E.B., I. Vergara, T. Schirado, and M. Morales. 1979. Nitrate movement in a Chilean agricultural area irrigated with untreated sewage water. J. Environ. Qual. 8:27-30.

Sheaffer, C.C., A.M. Decker, R.L. Chaney, and L.W. Douglass. 1979. Soil temperature and sludge effects on corn yield and micronutrient content. J. Environ. Qual. 8:450-459.

Shelton, J.E. 1976. An evaluation of sulfur-coated ureas as a preplant total seasonal nitrogen supply for trellised tomatoes. Soil Sci. Soc. Am. Proc. 40:126-129.

Shortall, J.G., and W.C. Liebhardt. 1975. Yield and growth of corn as affected by poultry manure. J. Environ. Qual. 4:186-191.

Siegel, R.S., A.A.R. Hafez, J. Azevedo, and P.R. Stout. 1975. Management procedure for effective fertilization with poultry manure. Compost Sci. 16(1):5-9.

Sims, T., and F.C. Boswell. 1978. Effect of bentonite on plant availability of sludge-borne heavy metals in soil. J. Environ. Qual. 7:501-505.

Sims, T., and F.C. Boswell. 1980. The influence of organic wastes and inorganic nitrogen sources on soil nitrogen, yield, and elemental composition of corn. J. Environ. Qual. 9:512-518.

Singh, K., I.S. Gill, and O.P. Verma. 1970. Studies of poultry manure in relation to vegetative production. I. Cauliflower. Indian J. Hort. 27:42-47.

Singh, K., M.S. Minhas, and O.P. Srivastava. 1973. Studies of poultry manure in relation to vegetable production. II. Potato. Indian J. Hort. 30:537-541.

Sjorgren, R. 1977. Application of sewage sludge to garden plots. Compost Science. Sept/Oct:26-31.

Slucky, D.J., and T.S. Newman. 1977. Effect of dried anaerobically digested sewage sludge on yield and element accumulation in tall fescue and alfalfa. J. Environ. Qual. 6:271-274.

Sommers, L.E. 1977. Chemical composition of sewage sludges and analysis of their potential use as fertilizers. J. Environ. Qual. 6:225-232.

Sommers, L.E., D.W. Nelson, and D.J. Silveiz. 1979. Transformations of C, N and metals in soils treated with waste materials. J. Environ. Qual. 8:287-293.

Sommers, L.E., D.W. Nelson, and K.J. Yost. 1976. Variable nature of chemical composition of sewage sludges. J. Environ. Qual. 5:303-306.

Stanford, G., J.O. Legg, and F.W. Chichester. 1970. Transformations of fertilizer nitrogen in soil. I: Interpretations of labeled and unlabeled nitrogen. Plant and Soil 33:425-435.

Stanford, G., and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stark, S.A., and C.E. Clapp. 1980. Residual nitrogen availability from soils treated with sewage sludge in a field experiment. J. Environ. Qual. 9:505-511.

Stewart, B.A., D.D. Johnson, and L.K. Porter. 1963. The availability of fertilizer nitrogen immobilized during decomposition of straw. Soil Sci. Soc. Am. Proc. 27:656-659.

Stewart, B.A., and A.L. Mathers. 1973. Salinity effects resulting from applying animal wastes on cropland. Agron. Abstr. p. 1983.

Stucky, D.J., and T.S. Newman. 1977. Effect of dried anaerobically digested sewage sludge on yield and element accumulation in tall fescue and alfalfa. J. Environ. Qual. 6:271-274.

Tanaka, A., K. Fugita, and K. Kikuchi. 1974. Nutrio-physiological studies on the tomato plant. I. Outline of growth and nutrient absorption. Soil Sci. Plant Nutr. 20:57-58.

Tenney, F.G., and S.A. Waksman. 1929. Composition of natural organic materials and their decomposition in the soil: IV. Nature and rapidity of decomposition of various organic complexes in different plant materials under aerobic conditions. Soil Sci. 28:55-84.

Terry, R.E., D.W. Nelson, and L.E. Sommers. 1981. Nitrogen transformations in sewage sludge-amended soils as affected by soil environmental factors. Soil Sci. Soc. Am. J. 45:506-513.

Tester, C.F., L.J. Sikora, J.M. Taylor, and J.F. Parr. 1977. Decomposition of sewage sludge compost in soil: I. Carbon and nitrogen transformation. J. Environ. Qual. 6:459-462.

Touchton, J.T., and F.C. Boswell. 1975. Use of sewage sludge as a greenhouse soil amendment. II. Influence on plant growth and constituents. Agric. Environ. 2:243-250.

Uehara, G., and G. Gillman. 1981. Implications for soil management. p. 72-74. In The Mineralogy, Chemistry, and Physics of Tropical Soil With Variable Charge Clays. Westiew Press, Inc., Boulder, Co.

Valdares, J.M.A., M. Gal, U. Mingelgrin, and A.L. Page. 1983. Some heavy metals in soils treated with sewage sludge, their effects on yield, and their uptake by plants. J. Environ. Qual. 12:49-57.

Wallace, T. 1961. The Diagnosis of Mineral Deficiencies in Plant By Visual Symptoms. Chemical Pub. Co. Inc., New York.

Wallingford, G.W., L.S. Murphy, W.L. Powers, and H.L. Hanges. 1975. Disposal of beef feedlot manure. Effects of residual and yearly applications on corn and soil chemical properties. J. Environ. Qual. 4:526-531.

War, G.M. 1967. Growth and nutrient absorption in greenhouse tomato and cucumber. Proc. Amer. Soc. Hort. Sci. 90:335-341.

Weber, D.F., and P.L. Gainey. 1962. Relative sensitivity of nitrifying organism to hydrogen ions in soils and in solutions. Soil Sci. 94:138-145.

Weil, R.R., and W. Kroontje. 1979. Organic matter decomposition in a soil heavily amended with poultry manure. J. Environ. Qual. 8:584-588.

Weil, R.R., W. Kroontje, and G.D. Jones. 1979. Inorganic nitrogen and soluble salts in a Davidson clay loam used for poultry manure disposal. J. Environ. Qual. 8:86-90.

Widdowson, F.V., A. Penny, and M.V. Hewitt. 1982. Results from the Woburn reference experiment. III. Yields of the crops and recoveries of N, P, K and Mg from manures and soil, 1975-79. Rothamsted Experimental Station Report for 1981, Part 2, 5-17. Rothamsted Experimental Station, Harpenden, England.

William, C.L., G. Carolyn, and T. Jane. 1979. Nitrate and ammonium concentrations of ground water resulting from poultry manure applications. J. Environ. Qual. 8:211-215.

Williams, R.J.B., and G.W. Cooke. 1961. Some effects of farmyard manure and of grass residues on soil structure. Soil Sci. 92:30-29.

Williams, S.P., and J.K. Greig. 1972. Organic and mineral fertilizers compared by yield, quality, and composition of spinach. J. Amer. Soc. Hort. Sci. 97(6):718-723.

Wong, M.H., C.M. Mok, and L.M. Chu. 1983. Comparison of refuse compost and activated sludge for growing vegetables. Agricultural Wastes 6:65-76.

Zane, F.L., and B.D. Doss. 1980a. Residual effects of dairy cattle manure on plant growth and soil properties. Agron. J. 72:123-130.

Zane, F.L., and B.D. Doss. 1980b. Coastal bermudagrass yield and soil properties as affected by surface-applied dairy manure and its residue. J. Environ. Qual. 9:157-162.

Zwarich, M.A., and J.G. Mills. 1982. Heavy metal accumulation by some vegetable crops grown on sewage-sludge-amended soils. Can. J. Soil Sci. 62:243-247.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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